THE WORKING OF ALUMINIUM

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PREFACE

THE present-day consumption of aluminium in industry is more than three times as great as that during the years immediately prior to the war; but saturation is not yet reached, and it follows that every year thousands of workers who have hitherto had no experience with aluminium are called upon to undertake its working. In several respects aluminium differs widely from other metals, and its special characteristics necessarily influence workshop practice. The procedure standard with other metals cannot always be adopted without modification, and experts in brass founding, iron welding, or steel turning, for example, must vary their methods when applying their arts to this new metal.

In this treatise the author has set out to explain the principles which should be followed in order to obtain the best results with aluminium in all branches of metal working, and to show the scope of the different processes as applied to this metal. Much of the information given refers to highly specialised industries, but the author is in the fortunate position of being in touch with expert workers in all trades, and it has been his business to study their methods, to examine their difficulties, and to keep himself informed of all new developments. It is thought, therefore, that though covering so

wide a field, the various chapters contain the essentials of best practice, which should be valuable alike to the manufacturer who must decide the general procedure, and to the worker faced with an unusual difficulty.

The text is amply illustrated by diagrams and photographs selected to show what can be done with the metal as well as to demonstrate particular points in the working processes themselves.

In addition to new and up-to-date matter on well-established processes, much information is given on processes which have not yet been practised to the extent warranted by their value. For example, anodic oxidisation, special uses of silicon alloys, and certain of the finishing processes described, have been introduced for a comparatively short time only, but are capable of wide application, and they offer alternatives to the designer which may facilitate production.

Coincident with the increase in the use of aluminium, there has been a wide activity of research into its properties, and of investigations into the special problems met with in its working. The results of this valuable work too often lie buried in scientific papers, often unavailable to those most able to benefit by them, and sometimes couched in terms which they cannot readily follow. More especially is this the case with developments in aluminium alloys, and it has therefore been thought desirable to commence with two chapters describing the properties of aluminium in the pure and alloyed forms. The study of aluminium alloys is the subject-matter of many voluminous treatises, but the author believes that these two chapters contain the bulk of the information necessary to enable the practical worker thoroughly to understand the metals with which he

is dealing. It has not been considered necessary to deal exhaustively with some of the more theoretic aspects of aluminium metallurgy, so that the reader will not find any serious discussion of the form of the equilibrium diagrams of the different alloys, nor detailed description of the metallurgical changes accompanying heat treatment and "modification". Instead, the author has concentrated upon the practical side of these matters, and the fullest information is given on the methods of carrying out these treatments and their effect on the mechanical properties of the different alloys; the influence of composition and impurities on such characteristics as porosity; the values of strength, etc., which should be obtained under practical conditions; and the methods of testing.

Finally, the author wishes to record his appreciation of the generous assistance given him by many Companies and individuals, the majority of whom are referred to by name in the text.

CONTENTS

CHAPTER I.

GENERAL PROPERTIES OF ALUMINIUM SHEET.

Physical Forms of Aluminium.

In considering the properties and methods of working of aluminium, it is necessary to distinguish between aluminium in the pure form and aluminium hardened by the addition of alloying constituents. Light aluminium alloys, such as are used in foundry work, are often referred to in common parlance as " aluminium," though they differ in physical properties from the pure metal as greatly as brass or bronze differ from pure copper. Since there is no colour difference, however, the aluminium alloys are indistinguishable in appearance from pure aluminium, and the absence of a generally accepted distinctive name intensifies the possibility of confusion.

Pure aluminium exists in three distinct physical forms, cast, hard worked and annealed. In the cast form it is a soft metal having a tensile strength of 5 to 6 tons per sq. in. and a fair degree of ductility. The extent of the ductility depends upon the rate of solidification, and metal which has been cooled rapidly from the molten state is usually superior to metal which has been allowed to solidify slowly. Micro-graphically, the difference between slow and quick cooling is shown in the size of the crystal grains, slowly cooled metal being characterised by a coarse structure of large-sized crystals, whereas rapidly cooled metal has a fine and more uniform structure.

Cast pure aluminium has little application in practice, and the majority of " aluminium " castings are made of aluminium alloy. A cast block in pure aluminium, however, represents

the first stage in the production of aluminium sheets, wire, extruded sections, and all other forms of the pure metal, and it is therefore interesting to trace the changes which occur in physical properties during the manufacture.

Cold and Hot Working.

If a pure aluminium casting is worked in the cold by hammering, rolling, etc., the metallic crystals become elongated, and coincident with this deformation there is a marked increase in the tensile strength, accompanied by a reduction in the ductility. The amount of deformation possible before the metal begins to crack is limited, but if the metal is given a preliminary hot working at about 400° C., the amount of subsequent cold working which it can withstand is very greatly increased. During hot working the amount of deformation possible is practically unlimited, for the metal is not hardened. When the hot worked metal is allowed to cool, its tensile strength will be found little higher than that of the casting, but its ductility, as measured by the percentage elongation on breaking, will be much greater.

The large degree of deformation which is possible when the metal is hot is a useful characteristic of the metal, and hot forging will often provide a simple solution to practical manufacturing difficulties. It may be remarked that this same characteristic also applies to the majority of aluminium alloys, though in such cases it is necessary to be careful of the temperature conditions, since at temperatures a little below their melting point many aluminium alloys lose their forging ability and become brittle.

The process of extrusion illustrates in an interesting way the amount of plastic deformation possible when the metal is hot. In this process a heated billet of the metal is placed in a cylinder closed at one end with a die plate, and by means of a hydraulically operated ram the metal is pressed through the die and emerges in the form of a long straight bar having the exact section of the hole in the die. In this way not only can

rectangular and circular bars be made, but angles, channels, tees and miscellaneous sections of all kinds, typical examples of which are shown in Fig. 1.

The general properties of the extruded metal are the same as those for hot forged metal, and the tensile strength will be some 5 to 6 tons per sq. in. with a high elongation. Where necessary, the strength can be increased by giving the extruded

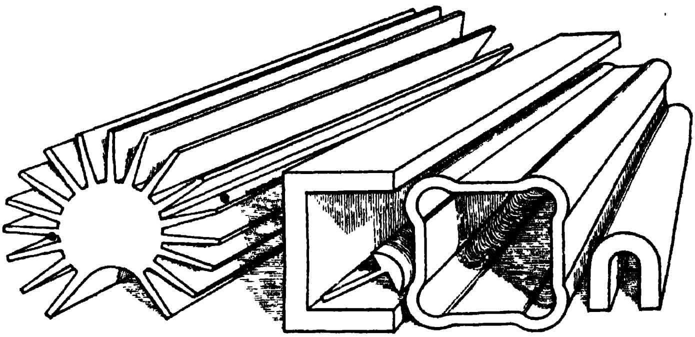

FIG. 1.—Typical forms of extruded aluminium.

section a few passes through the draw-bench dies, thereby doing upon it a certain amount of cold work.

Aluminium Sheet.

In the manufacture of aluminium sheet the process is first to cast a slab of suitable size; secondly to roll this hot to a thickness of about ¼ inch to ½ inch, according to the thickness finally desired; and thirdly to finish by cold rolling. During the cold rolling stage every pass through the rolls increases the hardness of the sheet, and hence the tensile strength of a very thin sheet would normally be considerably greater than that of a thick one. The softest aluminium sheet has a tensile strength of about 5 tons per sq. in., but by progressive cold working it is possible to obtain a strength of as much as 14 tons per sq. in.* Excessively high tensile strengths are,

* In wire drawing still higher strengths are attainable; the amount of cold work done often being sufficient to raise the strength of the wire to 20 tons per sq. in.

however, by no means desirable, for the increase in strength is accompanied by a decrease in ductility, and excessively cold worked metal would fracture so readily on bending that it would be of little value for practical use. For this reason arrangements are made whereby the strength of the hardest sheet used in normal practice does not exceed about 12 tons per sq. in., at which point the sheet is readily capable of being bent round a radius equal to its own thickness.

The manufacturer adjusts the tensile strength of the sheet firstly by varying the thickness where hot rolling finishes and cold rolling is commenced, and secondly by taking advantage of the fact that hardness due to cold working can be completely removed and the metal reduced to the soft condition by annealing, i.e. by heating to 350° or 400° C. and allowing to cool (cf. Fig. 2). It follows that it would be possible to provide a sheet of any thickness having any desired strength value, but in practice an adjustment of the rolling procedure to fulfil special requirements for each individual customer would be out of the question, and sheet is usually provided with three temper designations—soft, half-hard and hard. Intermediate tempers such as " medium soft " between soft and half-hard, and " medium hard," between half-hard and hard, may also be supplied, but the bulk of the needs of industry are met by the first three mentioned.

Specifications for aluminium of these tempers are issued by the British Engineering Standards Association, and are known as 2L17, 2L16 and 2L4 respectively. These were originally drawn up to cover the materials required for aircraft construction during the war, but they are now widely applied for aluminium for industrial purposes. The main requirements of these specifications are summarised in Table I.

Aluminium Wire.

Aluminium wire is made on the same broad principles as sheet, i.e. in three stages: casting, hot working and final cold working. The hot working stage is done by hot rolling the

cast billet to rod $\frac{3}{16}$-inch to $\frac{1}{2}$-inch diameter, and the cold working is effected by drawing the rod through dies of progressively diminishing size. Alternatively the hot working may be provided by the extrusion press, the wire being cold drawn from extruded rods.

TABLE I.

SUMMARY OF B.E.S.A. SPECIFICATIONS FOR ALUMINIUM SHEET OF DIFFERENT TEMPERS.

Specification No.	Description	Composition			Ult. Strength, Tons per sq. in.	Bend Test.
		Aluminium.	Iron + Silicon.	Other Impurities.		
		min.	max.	max.		
2L17	Soft aluminium sheet.	98%	1·75%	0·25%	5 to 6·5.	Strips must be capable of being bent back flat on themselves without cracking.
2L16	Half-hard aluminium sheet.	98%	1·75%	0·25%	7 to 8·5	Strips must be capable of being bent through 180° over a radius equal to half their thickness.
2L4	Hard aluminium sheet.	98%	1·75%	0·25%	Not less than 9	Strips must be capable of being bent through 180° over a radius equal to their thickness.

As in the case of aluminium sheet, intermediate annealing may be necessary during the cold drawing to limit the tensile strength, and this is particularly the case with aluminium alloy wires, since these harden very rapidly under cold work. The point is illustrated in Fig. 2 which shows the tensile strength results, obtained after each stage of drawing, for two pure aluminium wires and an aluminium alloy wire containing $1\frac{1}{2}$ per cent. of nickel. One of the pure aluminium wires was drawn from a $\frac{3}{8}$-inch rod down to ·08-inch diameter without annealing, and a strength of 31,000 lb./sq. in. was attained, and the second pure wire was drawn down to ·05-inch diameter with one stage of annealing, so that the finished tensile

strength is only 21,000 lb./sq. in. The high values of tensile strength attained in the case of the alloy wire is a striking

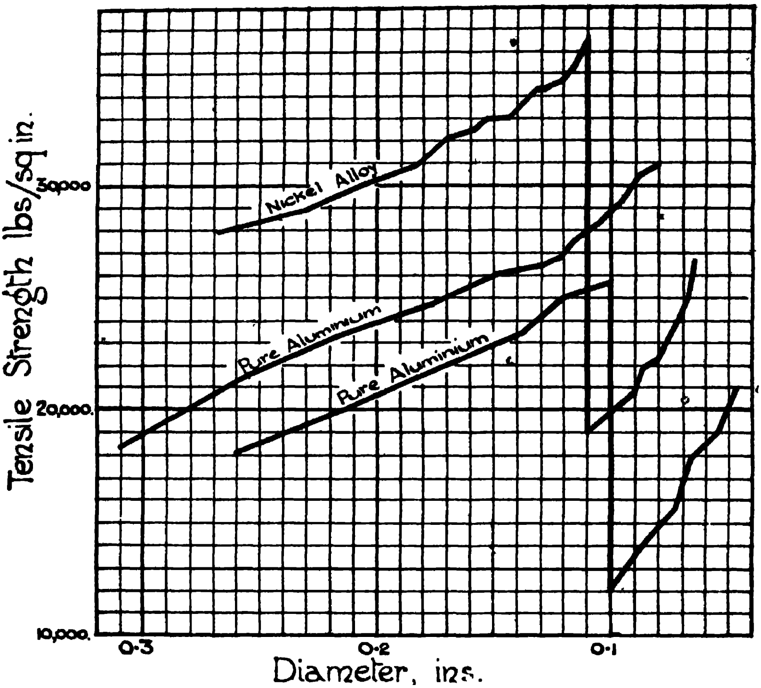

FIG. 2.—Tensile strength of aluminium wires under progressive cold work.

illustration of the effect of even a small addition of alloying constituent.

Tests for Sheet Metal.

In industrial practice the temper of sheet designed for any specific purpose is chosen in accordance with the amount of deformation which the sheet is to undergo, and, having decided by trial or experience the temper most suitable, conformity with this standard is ensured in subsequent consignments of sheet by routine tests on selected samples. The tests set out in

the British Engineering Standards Association's specifications comprise a tensile strength test on a specimen of the form shown in Fig. 3, and a bending test in which the specimen is bent over a wire whose diameter is varied according to the sheet thickness and the temper designation.

Both tests are simple to apply and effectively distinguish between the broad classes of temper dealt with by the specifications, but where finer discrimination is desired a number of other tests are occasionally adopted which are summarised as follows :

Elongation Test.—The percentage elongation of the test specimen after fracture, as measured by the distance between

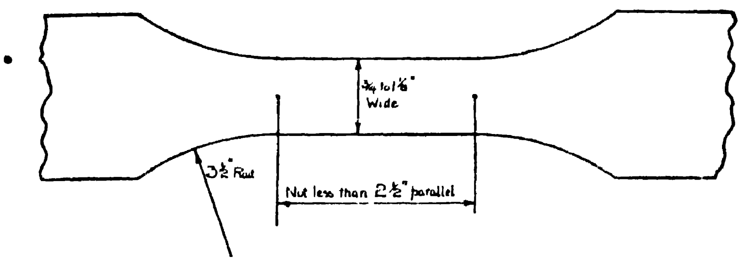

FIG. 3.—B.E.S.A. test specimen for sheet metal.

two gauge marks initially 2 inches apart, is sometimes taken as an indication of the ductility of the metal, but it is important to note that with a fixed gauge length the elongation measured depends upon the dimensions of the specimen as well as upon the temper. Thus, for example, a hard sheet of ·05-inch thickness would have about the same percentage elongation on 2 inches as a half-hard sheet ·015-inch thick, because the elongation depends largely upon the local necking at the point of fracture, and this increases with the section of the specimen. The difficulty can be overcome by using a longer gauge length for the thicker specimens than for the thin ones, and it has been stated that if the length between the gauge marks is made to vary as the square root of the sectional area of the specimen, then

the elongation values would be strictly comparable irrespective of the thickness. There are, however, several practical reasons for keeping the width of the specimen and the gauge length constant for all sheet thicknesses, and the elongation figures then become comparable only for sheet of the same thickness. The point is illustrated in Fig. 4, which shows the

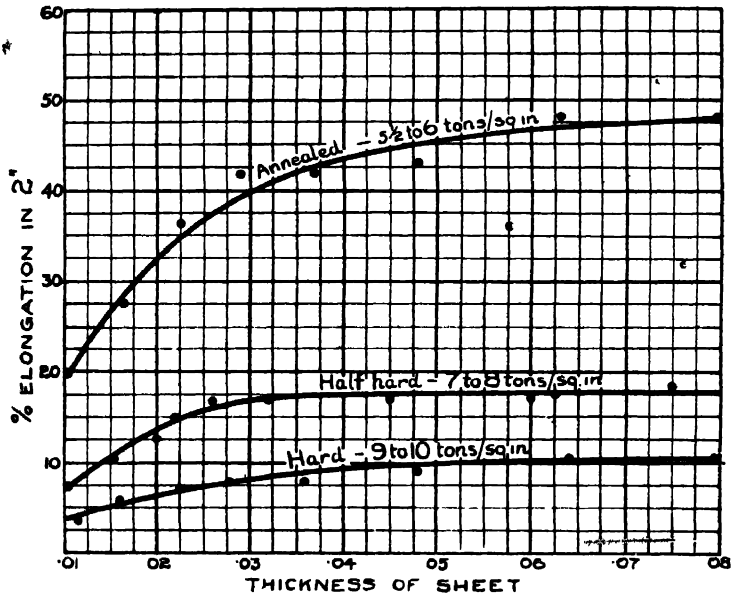

FIG. 4.—Variation in elongation on aluminium sheet of equal ductility but different thicknesses.

results of a series of elongation tests made on sheet of different thicknesses fulfilling the British Engineering Standards Association's specifications, the gauge length of the specimen being 2 inches and the width in each case 1 inch.

Scleroscope Hardness.—The scleroscope is an instrument in which a light hammer is allowed to drop upon the specimen and rebound. The height of the rebound is measured and this will be an indication of the hardness, for the softer the metal the greater will be the amount of energy absorbed when the hammer

strikes the metal and therefore the smaller will be the height of rebound. With aluminium the "magnifying" hammer is usually used because this gives higher readings than the "universal" hammer in the ratio of approximately 7 to 4 and is therefore more sensitive to small changes. The scleroscope test is a simple one which does not involve the shaping of a special test specimen, and the only precaution necessary is to arrange that the specimen shall be rigidly clamped to the base of the instrument to ensure that the hammer shall strike the surface normally. Given this, it would be expected that the results obtained would be independent of the thickness of the sheet and depend only on the hardness, except that, in the case of a very thin sheet, the effect of the hardened steel base to which the specimen is clamped may increase the readings. While this "anvil" effect is a well-marked phenomenon for sheet of about ·01 inch and under, it has been shown by Dr. Gwyer * that the readings at other thicknesses are affected by some little understood factor depending in some way on the sheet thickness. The point is illustrated in Fig. 5, which shows Dr. Gwyer's results on a series of specimens under increasing amounts of cold work, and it will be seen that while the tensile strength increases progressively and the elongation diminishes, the scleroscope values reach a well-defined maximum and then fall off until the anvil effect again causes a rapid increase in the values. The uniform variation in the other results measured indicates that the hardness of the sheet increases uniformly, and the variations in the scleroscope values can only be attributed to some phenomenon connected with the method. This, of course, does not mean that the method is valueless, but it means that the scleroscope number is only useful in conjunction with a knowledge of the sheet thickness. A scleroscope number of, say, 18, with a sheet 0·08-inch thick represents a definite degree of hardness for sheets of that

* "The Mechanical Properties of Sheet Aluminium," *Journ Birmingham Metallurgical Society*, Vol. VIII., No. 2, 1920.

thickness, though a scleroscope number of 18 for any other thickness would indicate a different degree of hardness.

The value of the scleroscope lies partly in its simplicity

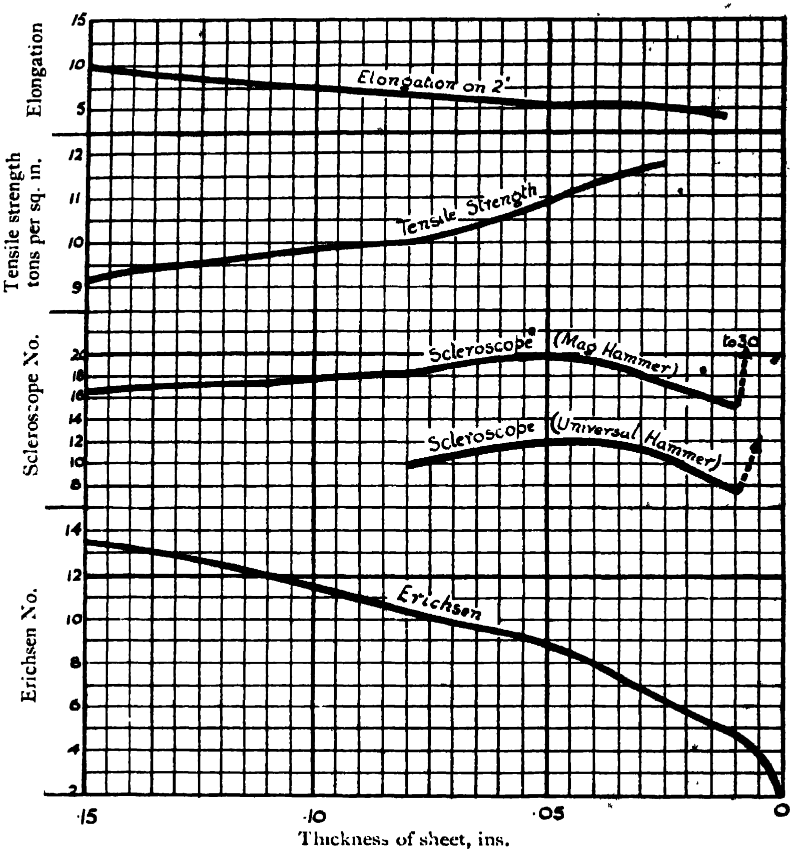

FIG. 5 – Variations in physical properties of aluminium sheet under progressive cold work (Gwyer).

and rapidity of application, and partly in its extreme sensitivity to changes of temper, so that even small variations in the hardness at different parts of the same sheet may be detected.

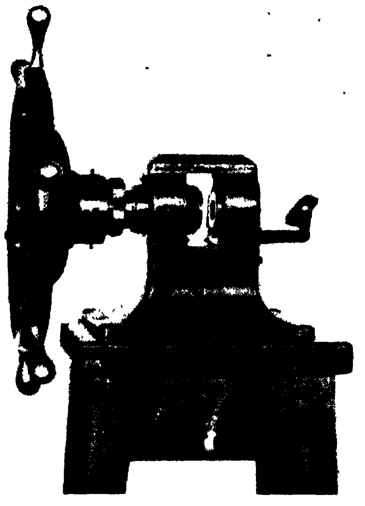

FIG. 6.—Erichsen testing machine.

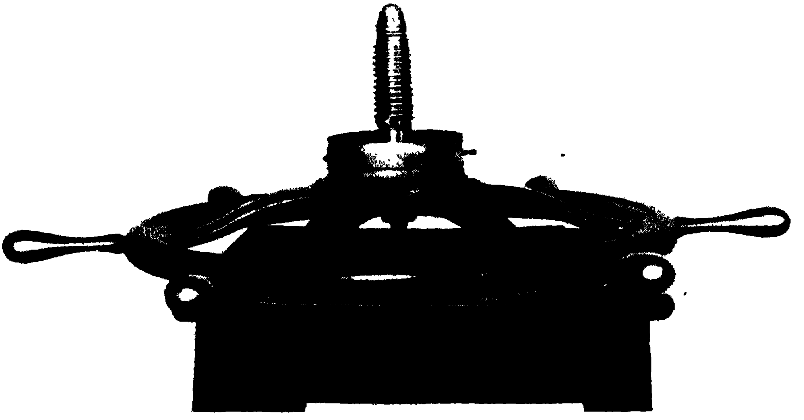

FIG. 7.—Ram and handwheel of the Erichsen machine.

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The Erichsen Test.—It will be appreciated that the desirable property of a sheet from the metal-workers' view-point is neither the tensile strength, nor the ultimate elongation, nor the particular kind of hardness indicated by the scleroscope, but rather a combination of properties which might be described as the " workability " of the metal. The press worker, the spinner, the panel beater, and so on, all desire to know the amount of deformation which the specimen is capable of withstanding, and an attempt to measure this quantity directly is made in a machine invented by a Norwegian engineer, Mr. A. M. Erichsen, which has a wide application. The machine is shown in Fig. 6, and consists essentially of a hardened steel punch which is brought up to the sheet by means of a hand-wheel and a screw (shown in Fig. 7), and pressed into the test specimen, forming a dome-like impression. The bulging operation is watched in the mirror, which can be seen in Fig. 6, until the point of fracture is reached, when the depth of impression is read off on a scale. The " Erichsen number " is the depth in millimetres at the instant when the dome bursts.

This value is dependent upon the sheet thickness as well as upon the quality of the metal itself, so that, as with other tests, the results can only be interpreted in conjunction with a knowledge of the thickness. The test is, perhaps, less satisfactory than others for detecting slight differences in temper because it is not very sensitive, and the indentation of a hard sheet is only from 25 per cent. to 50 per cent. less than that for a dead soft sheet of the same gauge. Nevertheless, the method has the great practical advantage that the process of testing approximates to the actual process of working. Thus the appearance of the dome during and after test is an indication of the probable behaviour of the metal, and such defects as excessive grain-size, not readily detectable by any other test, would be shown up in the domed test piece.

Annealing Sheet Aluminium.

During the working of sheet aluminium into shaped bodies by drawing, beating, or other means, the metal hardens in

accordance with the principles explained, and it would be the aim to select such a temper to start with that the finished articles are dead hard. If, however, the amount of shaping to be done is excessive, it may be found that sheet of the softest temper becomes too hard for further work before the shaping is completed, and a process of annealing is then necessary. Annealing is extremely simple, and merely involves the raising of the temperature of the metal to about 400° C., and cooling either naturally or by plunging into water. No scale is formed during this heating, so that the pickling process necessary with iron and copper is not required, and the metal is ready for continued work immediately it has cooled.

If the shape and size of the article permits, the best heating medium is a muffle furnace in which the metal is uniformly heated by radiation, and the temperature can be adjusted and measured accurately by pyrometer. In the case of the large sheets used by panel beaters a gas blow-pipe is used which is played upon the sheet until its temperature, as gauged by some rough and ready workshop test, attains the requisite value. A common test of this kind is to rub the metal with a dry match stick from time to time, since this becomes charred and leaves a black mark on the metal at a temperature sufficiently high to ensure adequate softening.

In the case of a repetition process, where a large number of identical objects are to be produced, the annealing should result in a constant degree of softening for each batch of metal dealt with, and for this reason it is desirable to use a muffle furnace, a bath of molten salts, or some other device which can be maintained at a definite temperature, and with which the period of exposure to the heat can be accurately adjusted. The time required depends upon the temperature employed, and to some extent upon the purity of the metal. Carpenter and Taverner * have shown that with metal of 98 to 99 per cent. purity, complete softening requires a time of well over 500

hours if the annealing temperature is 250° C., but that at 350° C. about 24 hours is sufficient. With still higher temperatures an even smaller time of exposure is required, as is indicated in the summary given in Tables II. and III., and later

TABLE II.

TENSILE STRENGTH OF ALUMINIUM SHEET, IN TONS PER SQUARE INCH, AFTER VARIED EXPOSURE TO DIFFERENT TEMPERATURES. (CARPENTER AND TAVERNER.)

Annealing Temp. °C.	Time of Exposure, Hours.							
	0	1	6	12	24	48	72	96
300	10·83	9·16	8·10	7·34	6·50	6·07	5·89	5·80
350	10·83	7·02	6·06	6·00	5·92	5·82	5·95	5·85
400	10·83	6·10	6·08	6·07	6·07	5·86	5·76	5·84
450	10·83	6·37	6·22	6·09	5·92	5·77	5·70	5·69
500	10·83	6·20	5·90	5·81	5·83	5·76	5·80	5·74
550	10·83	5·96	5·82	5·94	5·75	5·73	5·75	5·78

TABLE III.

ELONGATION IN 3 INCHES CORRESPONDING TO THE TENSILE STRENGTH VALUES OF TABLE II.

Annealing Temp. °C.	Time of Exposure, Hours.							
	0	1	6	12	24	48	72	96
300	7·0	10·2	15·0	20·3	29·3	38·7	41·2	41·5
350	7·0	28·3	40·0	40·7	41·2	42·3	42·0	42·2
400	7·0	38·8	37·3	39·8	39·2	40·0	39·2	40·7
450	7·0	37·0	36·7	37·2	39·5	39·3	39·8	40·7
500	7·0	34·7	37·0	36·8	39·0	37·7	39·1	38·5
550	7·0	37·0	37·7	35·5	35·7	36·2	37·3	36·2

work by Carpenter and Coldron Smith * has shown that with sheet of higher purity and, therefore, more representative of normal conditions, annealing takes place more rapidly still.

An examination of the figures indicates that the bulk of work hardening is removed during the first hour, and economic

considerations would suggest that exposures at 350° to 400° C. for a period of about one hour would amply meet normal practical requirements. The exact period of time required will depend upon the size of the article and the heating means adopted. For example, if a large number of flat sheets are packed in a stack in a small muffle initially at 350° C. a longer period of exposure would be necessary than for a small number of articles more openly packed, in that it would take a considerable time for the mass of metal to attain the muffle temperature.

The figures of Tables II. and III. suggest that possibly an even more economical process would be to use a high temperature of, say, 500° to 550° C., since sufficient softening for practical purposes is then obtained in a very few minutes, but there is a danger that in certain circumstances this may result in the production of an inferior physical structure, which, though not detectable by tensile or elongation measurements, may affect the working properties of the metal.

The condition referred to is an abnormal growth of the metallic crystals, and this would not be visible until the metal is subsequently worked (for example, by passing it through a draw press) when, under the deformation, the large grains become visible to the naked eye as a roughening of the surface. The production of this excessively large crystal growth depends upon the temperature of annealing, the purity of the metal, and also upon the degree of deformation which the metal had undergone previously to the annealing. The phenomenon has been examined by Carpenter and Elam,* and others, and, while the scientific explanation of the behaviour is complicated, the effect from the practical point of view may be stated as follows :

For every annealing temperature there is a certain critical degree of deformation which gives the maximum grain growth. If the annealing temperature is high the abnormal growth may occur if the amount of deformation which the metal has undergone is small, and the lower the temperature of annealing the

* *Journ. Inst. Met.*, Vol. XXIV., No. 2, 1920, p. 83.

greater will be the critical degree of deformation favourable to abnormal growth. Below a certain value (approximately 350° C.) it becomes practically impossible to produce excessive crystal growth whatever the amount of deformation.

An important consideration is the fact that in the manufacture of any article from sheet metal, different parts of the finished object will have undergone different amounts of cold work. In a drawn cylindrical shell, for example, the sides have undergone considerably greater deformation than the bottom, and should annealing be necessary it is possible for the conditions favourable for exaggerated crystal growth to occur at certain parts while not at others. A very interesting case of this sort is reported by A. P. Knight in *Chemical and Metallurgical Engineering*, 2nd November, 1921, where a drawn aluminium shell, after annealing at 800° F. (426° C.) for 45 minutes, developed a roughened surface at certain points on subsequent working. Micrographic examination indicated large grain growth at the shell bottom which had undergone very little working, while the sides, which has been strongly worked, exhibited the regular structure of ordinary annealed metal.

The difficulty was completely overcome by reducing the annealing temperature to 700° F. (371° F.), the time of exposure being increased to 60 minutes. It was then found that the crystal grains at all points were fine and uniform, and no further trouble was experienced with roughened surfaces.

Purity of Sheet Aluminium.

The standard specifications of the British Engineering Standards Association, to which reference has already been made, give the minimum purity of aluminium sheet as 98 per cent., but in England, at least, manufacturers rarely take full advantage of the latitude permitted them in this respect, and the bulk of British-made sheets would not contain more than 1 per cent. of impurities. The point is of importance in that one of the chief advantages of aluminium in many applications

is the great resistance which it exhibits to corrosive influences, and these properties depend to some extent upon the purity. As with most materials, the greater the purity the more resistant the metal is to attack. It is thus common practice in the construction of vessels used for the manufacture of chemicals, and in other applications where the metal is exposed continuously to strongly corroding conditions, to employ sheet of special purity containing not less than 99·5 per cent. of aluminium. Such high purity metal is, however, not necessary for the majority of the applications of aluminium.

The difference in the mechanical properties of sheet of 99·5 per cent. purity and of 99·0 per cent. purity is not marked, although, in accordance with the general rule, there would be a tendency for a greater softness and ductility in the material of higher purity.

Profound changes in mechanical properties are, however, obtainable by the addition of alloying constituents and, as has already been noted (Fig. 2), the addition of only 1½ per cent. of some other metal may greatly increase the tensile strength. Very many different alloy compositions are employed, some of which are of complicated type by which a very high tensile strength, comparable with that of steel, is obtainable by special treatment. Apart from these it is possible, with quite simple alloys, to obtain sheets which differ little in weight from pure sheets of the same thickness but have double the strength.

Alloy Sheets.

The general properties of simple alloy sheets can be illustrated by reference to the aluminium-copper series of alloys containing up to about 8 per cent. of copper, the remainder being aluminium. Such alloys are readily rolled by the same process as is employed for pure aluminium, though more frequent annealing is required during the working owing to the greatly increased rate of hardening. As with pure aluminium, the strength increases with cold working and the effect of work

hardening is removed by annealing. Comparative values, due to Carpenter and Edwards, between the properties of pure aluminium sheet and sheet containing 3·74 per cent. of copper are given in Table IV.

In the simple aluminium-copper series, the alloy containing about 4 per cent. of copper is the most valuable, because with a smaller percentage of copper the strength is not so high, while with a higher percentage the working qualities of the meta are greatly reduced without any substantial increase in tensile properties.

TABLE IV.

COMPARATIVE PROPERTIES OF SHEETS OF PURE ALUMINIUM AND OF COPPER-ALUMINIUM ALLOY. (CARPENTER AND EDWARDS.)

Sheet Composition.	0·05 in. thick.		0·10 in. thick.		0·25 in. thick.	
	Hard.	Annealed	Hard.	Annealed.	Hard.	Annealed.
	Tensile Strength Tons per sq. in.					
Copper alloy (3·74 per cent Cu)	18·56	11·66	17·58	11·00	15·60	10·76
Pure aluminium	9·34	5·83	9·18	5·90	8·36	5·91
	Per Cent. Elongation in 3 ins.					
Copper alloy (3·74 per cent. Cu)	4·0	24·7	4·0	21·0	4·0	24·0
Pure aluminium	3·7	36·3	6 3	31·0	10·6	41·0

The copper alloys may be taken as typical of binary alloys in general, simple alloys of aluminium and other metals behaving very similarly and giving test results differing only in degree. Such alloys have, however, little extensive application in practice, for though they are much stronger than pure aluminium, they are generally more expensive, are not so easily worked, and in many cases do not exhibit so strong a resistance to corrosion. For such applications as cooking utensils, or the bodywork of motor cars, pure aluminium sheet provides ample strength, and its great ductility and absence of rusting

are valuable features, not readily to be sacrificed. It goes without saying that even with cooking utensils hardness is a desirable quality, if only to improve resistance to accidental blows, but up to the present this is not obtainable without sacrifice in other directions.

In America, cooking utensils and similar objects are sometimes made of alloys containing 1 per cent. to 1½ per cent. of manganese, which are found to withstand corroding conditions comparatively well. The tensile strength of such sheets in the hard condition is about 14 tons per square inch for No. 10 s.w.g. thickness, with higher values for smaller gauges, and in the annealed state the strength is 8 to 9 tons per square inch, with an elongation of 20 per cent. The material is thus much stronger and harder than pure aluminium, but it is by no means so readily worked, and where much shaping is to be done, additional annealing operations may be necessary. In press working, for example, a greater number of press operations is required so as to include one or more stages of intermediate annealing, and the working costs are, therefore, appreciably greater. It is questionable whether the extra expense is justified, since it is possible that for the same cost an equally rigid utensil might be made with a thicker gauge of pure aluminium.

Though, as has been stated, aluminium alloys are not generally so resistant to corrosion as pure aluminium, this is not invariably the case, and simple silicon alloys of aluminium containing from 5 per cent. to 10 per cent. of silicon are exceptionally good from this point of view. Silicon alloy sheets have recently been adopted to some considerable extent for use on ship board and other places where conditions are particularly severe.

Ternary alloys of aluminium are not greatly used in the rolled condition, but mention may be made of the 3 : 20 alloy, investigated at the National Physical Laboratory during the war, which is an outstanding example of the high tensile strengths possible with alloys not subjected to special treat-

ment. This alloy contains 3 per cent. of copper, 20 per cent. of zinc, and the remainder aluminium, and in spite of the high percentage of alloying constituents it was found possible to roll this material into sheets of any desired thickness. The tensile strength of the hard rolled sheet lies between 25 to 30 tons per sq. in. with elongation values on 2 inches varying between 15 to 12 per cent. for thicknesses from 0·10 inch to 0·05 inch. It would be expected that with material of such extreme hardness, cold working by spinning would be out of the question, but it is found that annealing at 250° C. for about 30 minutes, though producing a comparatively small reduction in the tensile strength, will greatly restore the ductility, the elongation increasing to 18-22 per cent. for the sheet thicknesses mentioned. It may be remarked that unlike pure aluminium the ductility of annealed sheet in this alloy depends, to some extent, upon the temperature of annealing, and annealing at, say, 450° C. results in greater hardness and less ductility than annealing at much lower temperatures.

Although this material has such remarkable properties it has not been employed to any great extent, partly owing to the difficulty of rolling, and partly because it is rather susceptible to corrosion. This latter difficulty is not, in itself, a very serious objection, for steel itself is one of the most readily corrodible of metals, and if there were no alternative, the 3 : 20 alloy would be used with the same precautions against corrosion as are adopted with steel. However, for purposes where extremely high strengths are desirable, such as aircraft construction, less corrodible alternatives are available in which equally high strengths are obtained by a process of heat treatment, and though such alloys are necessarily costly, this is often considered of secondary importance.

Heat Treated Alloy Sheets.

Certain of the alloys of aluminium can be hardened by a process which is almost equivalent to the tempering process applied to steel. For example, the simple 4 per cent. copper

alloy sheet, which in the annealed state has a tensile strength between 10 to 12 tons per sq. in., may attain a strength of from 19 to 20 tons per sq. in. on heating for one hour at 500° C., quenching in water and allowing to " age " for five days. The difference between this process and the ordinary tempering of steel is that immediately after quenching the strength of the aluminium-copper alloy is very little different from that of an annealed sheet, and the higher strength is attained gradually when the specimen is allowed to stand at the ordinary room temperatures.

It is not necessary to enter into the scientific reasons for this phenomenon, except to say that it has been ascribed to the different solubility at different temperatures of the chemical compound $CuAl_2$ which is present ; and in alloys containing magnesium similar effects are traceable to the compound Mg_2Si formed with the silicon present as an impurity in the aluminium.

It is to these compounds that the behaviour of the well-known alloy, duralumin and others of similar nature, is attributed.

Duralumin contains approximately 4 per cent. of copper and ½ per cent. each of magnesium and manganese, the remainder being aluminium and the normal impurities, and though the total percentage of alloying ingredients is small, so that its specific gravity is very little higher than that of pure aluminium, it is capable of attaining a tensile strength of at least 25 tons per sq. in. with a substantial amount of ductility, by means of a tempering process similar to that described. It is, moreover, little more susceptible to corrosion than pure aluminium, while, as it is readily softened by annealing, it is capable of being worked with a fair degree of ease.

The tempering or " normalising " process, as it is often termed, consists of heating the metal to between 480° to 500° C., quenching in water and allowing to " age " for a period of about four days. The temperature is important, for if it is

less than 475° C. the full hardening effect is not attained, while if the temperature exceeds 500° C. there is a grave risk of causing brittleness and surface blistering. Apart from this also, the alloy begins to melt at about 545° C., so that above 500° C. the metal is closely on the point of melting and distortion is likely to occur. The range of temperature available is, therefore, very restricted, and great care must be taken to work within the narrow margin.

The usual method is to immerse the object in a bath of molten salts—a half and half mixture of potassium and sodium nitrates being most common—and the temperature must be adjusted accurately by a pyrometer. The time of immersion is only that necessary to raise the object to the temperature of the bath, and for thin plates, strip, etc., 10 to 15 minutes is sufficient. No disadvantage is likely to arise through overlong exposure, so that when the object is large—a heavy forging for example—exposure from one to two hours is desirable to ensure that the required temperature shall be attained throughout.

The material is then quenched, and immediately after quenching the strength is about 16 tons per sq. in., which is about the same as that for annealed duralumin. The strength, however, commences rapidly to increase, and after about four days a value of from 25 to 30 tons per sq. in. is attained. This strength is not produced by cold working, and hence is independent of the sheet thickness, and it is not accompanied by any loss of ductility. Indeed, the ductility of the heat-treated sheet, as indicated by elongation measurements, is usually greater than that of the same material in the annealed state.

Heat-treated sheet can be cold rolled, and its strength then increases still further, with a sacrifice of ductility, as with other metals, and this point is illustrated in Table V., which gives test results on duralumin of various physical conditions published by the Baush Machine Tool Company, Springfield, U.S.A., who are manufacturers.

Hardness, due either to heat treatment or to cold working, is removed by heating to a temperature of approximately 350° C., and allowing to cool slowly or by quenching in water. It may be remarked that the annealed condition could always be attained by very slow cooling, even though the heating temperature were 500° C.; but in practice it would be inconvenient to arrange for the cooling to be sufficiently slow, and in a sheet annealed by slow cooling from such a temperature a certain amount of hardening during the course of time would

TABLE V.

TEST RESULTS ON DURALUMIN OF DIFFERENT PHYSICAL CONDITION.

Condition.	Dimensions of Specimen.	Elas. Limit, Tons per sq in.	Ult. Strength, Tons per sq in.	Per Cent Elongation.	Brinell Hardness.	Scleroscope Hardness.
Annealed.	·520 × ·218	10·8	15·5	16·5	57	—
	·520 × ·100	10·7	14·5	15·0	—	14
	·522 × ·078	10·0	13·4	17·5	—	11
	·520 × ·060	—	13·7	18·0	—	10
	·520 × ·040	—	13·9	17·5	—	10
Heat-treated and aged.	·487 × ·253	15·7	28·2	23·0	100	—
	·490 × ·126	16·2	27·4	22·5	100	—
	·508 × ·076	17·2	28·7	20·0	—	23
	·507 × ·050	18·6	29·1	19·0	—	23
	·811 × ·042	17·6	29·0	18·5	—	23
Heat-treated, aged, and cold rolled.	·491 × ·252	26·6	30·2	6·5	130	—
	·488 × ·127	28·3	33·0	4·5	140	—
	·508 × 102	24·1	31·3	7·0	140	—
	·507 × ·078	27·8	32·4	5·5	—	39
	·508 × ·052	29·9	34·0	3·5	—	42

invariably occur. If the annealing temperature is adjusted carefully within the range of 350° to 380° C., however, no difference is made as regards the stability of the softening whether the material is cooled rapidly or slowly. Almost as much attention must be given to adjusting the temperature of annealing as the temperature of "normalising," because if the temperature is too low the softening effect is not so large as it should be, while if the temperature exceeds 420° C. there will be a tendency for hardening with time.

Annealed sheet, of course, hardens under cold working, and where much shaping is to be done several annealings may be necessary. The cycle of annealing, work hardening, re-annealing and so on, does not in any way harm the metal, and when the shaping is finished the whole article can be "normalised" by quenching from 490° C. when it will attain its maximum strength.

Where the amount of shaping to be done is small and the work can be done within, say, one hour of heat treatment, advantage may be taken of the fact that immediately after quenching, in the process of "normalising," the material is quite soft and readily workable. If the work is completed while the object is passing through this stage, it hardens normally without further heating in the finished shape, and where this practice is possible it is greatly preferable to annealing and subsequent "normalising" for many reasons, among which is the elimination of any danger of distortion which is always possible during heat treatment.

Various modifications of duralumin have been discovered, among which is the very interesting series of alloys described in the Eleventh Report to the Alloys Research Committee,* which was the outcome of an attempt to combine the properties of duralumin with those of the 3 : 20 alloy. A result of this research was the discovery of an interesting alloy, the composition and physical properties of which are included in Table VI. under reference L29. The table provides a comparison between *minimum* mechanical properties of this and other alloys, and it will be seen that the "High Tensile" alloy will have a tensile strength of 32 tons per sq. in. as compared with 25 tons per sq. in. for duralumin, and for the non-heat-treated 3 : 20. In point of fact, with alloys of this composition tensile strengths of 38 tons per sq. in. and over have been obtained with elongation values well above the minimum figures given in the table, but these alloys are so difficult to

* *Institute of Mechanical Engineers*, 1921.

TABLE VI.

SUMMARY OF B.E.S.A. SPECIFICATIONS FOR ALUMINIUM ALLOY SHEETS.

Specification No.	Alloy Description.	Composition.	Impurities.	Specific Gravity.	Ult. Strength, Tons per sq. in.	Elongation on 2 ins.
2L3	Duralumin sheet (heat-treated).	Copper, 3·5 to 4·5 Manganese, 0·40 „ 0·70 Magnesium, 0·40 „ 0·70 Aluminium, Remainder.	Iron not to exceed 0·5%.	2·85	25	Less than ·02 in. thick, 8% ·02 in. to ·048 in., 12% ·048 in. and over, 15%
L26	Y-alloy sheet (heat-treated)	Copper, 3·5 to 4·5 Nickel, 1·8 „ 2·3 Magnesium, 1·2 „ 1·7 Aluminium, Remainder.	Iron, 0·5% max. Silicon, 0·5% max. Other impurities to total not more than 0·1%.	2·85	22	Less than ·02 in. thick, 8% ·02 in. to ·048 in., 12% ·048 in. and over, 15%
L28	3/20 alloy sheet.	Copper, 2·7 to 3·3 Zinc, 18 to 21 Aluminium, Remainder.	Iron, 0·5% max. Silicon, 0·5% max.	3·15	25	Less than ·02 in. thick, 8% ·02 in. to ·048 in., 12% ·048 in. and over, 15%
L29	High-tensile alloy sheet (heat-treated).	Copper, 2·2 to 3·0 Zinc, 16 to 20 Manganese, 0·3 to 0·55 Magnesium, 0·25 „ 0·60 Aluminium, Remainder.	Iron, 0·5% max. Lead and tin together not to exceed 0·1%.	3·15	32	Up to ·02 in. thick, 9% ·02 in. to ·048 in., 11% ·048 in. and over, 13%

produce under practical conditions that they have no application in industry. The figures given are laboratory results, and it is doubtful whether sheet of practical size could be produced commercially.

From the point of view of resistance to corrosion particular interest is attached to the "Y" alloy referred to in Table VI., which we shall deal with more particularly as a casting alloy, but which calls for reference here in that it also is capable of being rolled into sheet and drawn into wire. Sheets of this alloy, after heat treatment, attain strengths comparable with duralumin, while providing an even greater resistance to corrosion, and having a greater capacity to retain their strength at elevated temperatures.

CHAPTER II.

ALUMINIUM CASTING ALLOYS.

Cast Pure Aluminium.

In the cast form aluminium of normal 98-99 % purity has a tensile strength of 5 to 6 tons per sq. in. and an elongation of 25 per cent. to 45 per cent. on 2 inches, and, as in the case of sheet metal, much greater hardness, accompanied by a reduction in the elongation, is obtainable by alloying. The reduction of ductility is not a serious disadvantage, as it is in the case of sheet metal, for castings are not normally subjected to plastic working, while as regards the physical properties most useful for casting metals, it is found that alloying provides a definite improvement. Thus, aluminium alloys are, in general, much more readily handled in the foundry, and are also more easily machined. In view of these improvements by so simple an expedient as alloying, pure aluminium is not often used in the cast form, although it is of value in certain special applications. Normally it can be assumed that cast parts employed in all branches of industry under the general designation of "aluminium castings" are, in actual fact, made in an aluminium alloy.

In this treatise we shall deal only with light alloys, i.e. alloys containing at least 70 per cent. of aluminium, for while aluminium enters into the composition of many important heavy alloys, such as aluminium bronze (containing 90 per cent. of copper with 10 per cent. of aluminium), such alloys differ too greatly in weight and general properties from aluminium to be classed with the metals ordinarily dealt with in an aluminium foundry.

Testing Castings.

In reviewing the general properties of aluminium alloy castings, consideration must be given not only to the effects of additions of different quantities of different alloying constituents, but also to the methods of manufacturing the castings. The properties of an aluminium alloy with fixed composition are widely variable according to the methods and conditions of casting, and, indeed, it is not unusual to find that the properties of test specimens cut from different parts of the same casting are appreciably different. In practice it is hardly practicable to cut specimens from the finished work for test, although in the case of a new design for an important aircraft part, for example, it is sometimes required that the first casting made shall be cut up and tested. This is a test for moulding practice only, and successful results prove nothing more than that with the mould design adopted satisfaction is attainable. Such tests do not ensure that all subsequent castings from the same mould will be equally satisfactory, and additional checks are, therefore, necessary. These would include a minute examination for visible defects (hair cracks, etc.), a hydraulic test for porosity, and tensile tests on specimens specially cast from the same melt at the same time as the casting itself.

A test specimen is often poured in the same mould, and at the same time as the casting, the specimen or "coupon" being connected with the main casting by a runner, which is cut through after the whole has solidified and the mould turned out. The specimen may be cast to the true shape required for testing so that it is tested without any preliminary machining, the object being to preserve the outer skin which is often harder and stronger than the metal of the centre.

It is thought that in such circumstances the test specimen closely represents the metal of the casting itself, but since the different parts of the same casting may have strengths varying by as much as 50 per cent. * the test "coupon" can provide

* Results of tests on this point are to be found in *Journ. Inst. Met.*, 1924, No. 2, p. 38.

no reliable indication of the strength of the weakest section. This is the reason for the alternative practice in which the complication of forming the test coupon with the casting is avoided, the specimens being cast separately under conditions which will eliminate as far as possible the influence of moulding practice. In England the usual practice is to cast specimens in a warmed cast-iron mould, 1 inch diameter and 7 inches to 9 inches long, just before the casting itself is poured, and the specimen, after cooling, is finally machined to the dimensions shown in Fig. 8 before testing. The results then obtained may be very different from the properties of the casting itself, for the outer skin has been removed, the rapid chilling effect of the iron mould is not present in the casting moulded in sand,

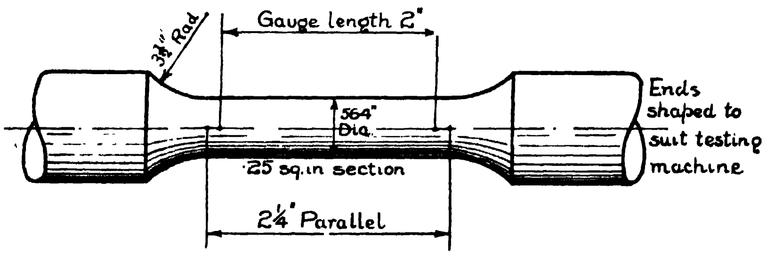

FIG. 8.—B.E.S.A. standard test specimen for aluminium casting alloys.

and, the simplicity of shape of the test specimen will involve little chance of porosity, draws, or other foundry effects possibly present in the casting itself. In brief, it is the view in England that, as it is impossible by any means short of destroying the work, to determine the strength of the metal in the casting itself, it is better to abandon the attempt and employ a test which shows the *capability* of the metal for producing good castings. If, even when poured in ideal conditions, the test specimen shows results below reasonable requirements, the rejection of the corresponding casting would be justified on the grounds that the metal has been oxidised, poured at too high a temperature, wrongly mixed, or in some other way rendered incapable of forming good castings. It is true that

if, on the other hand, the test specimen gives satisfactory results, the casting itself is not necessarily sound, but it will probably be so if under hydraulic test no porosity, cracks or other *moulding* defects, are shown.

Chill and Sand-Cast Specimens.

The physical properties of a casting are dependent very largely upon the crystal size, and, in general, metal with a coarse crystalline structure is less strong and less ductile than one with a close-grained formation of the crystals. The size of the crystals depends very largely upon the rate of cooling, and the more slowly the mass of molten metal is allowed to solidify the larger the crystals will grow. It follows that, other things being equal, a casting made in an iron mould will normally be stronger than one cast in sand, owing to the much greater rate of heat conduction through the metal mould.

In comparing the relative physical properties of different alloys, therefore, it is important that the type of mould be specified and, following British practice, the figures for strength etc., in the following paragraphs will be the figures obtained on machined chill cast specimens, unless otherwise stated. It is thought that greater consistency is obtainable with chill cast specimens, so that a more reliable comparison is attained. The difference between chill-cast and sand-cast results is strikingly illustrated in Figs. 9 and 10, which give values on both types of specimen.

Hardness Determination.

The most important physical properties to be studied are tensile strength, elastic limit and percentage elongation. Hardness determinations are not of very great value in the case of castings, because the test is necessarily limited to a very localised spot, and it does not necessarily follow that the hardness of this particular spot is representative of the hardness of the whole of the metal. It is found that very wide variations in hardness, even wider than the variations in tensile strength, occur at different points of the same casting.

Where hardness determinations are made, the Brinell test is most usual. In this test a hardened steel ball is pressed into the metal under a known load, and the diameter of the impression is measured. From this, the value is calculated for the intensity of load which has been sustained, and this figure is termed the hardness number. Theoretically, the hardness number as so determined should be independent of the pressure applied, but in actual practice it is found that the value calculated does vary to some extent according to the load. With all hard materials the usual load employed is 3000 kgs., but with aluminium and its alloys a common practice is to reduce this to 500 kgs., keeping the same ball diameter (10 mm.).

TABLE VII.

HARDNESS OF CHILL-CAST ALUMINIUM ALLOYS.

Composition.	Brinell Hardness.	Scleroscope No. (mag. hammer).
Pure-cast aluminium	25	5·6
13 Zn 3 Cu (L5 alloy)	70	24
Y-alloy	75	27
,, heat-treated	100	35
4 Cu	45	14
8 Cu	65	22
12 Cu	80	23
14 Cu 1 Mn	90	22
5 Si	40	—
12 Si	55	15
,, modified	60	21
4 Cu 3 Si	50	—

The hardness number obtained with a 500 kgs. load is found to be about 10 per cent. lower than that obtainable with a 3000 kgs. load.

Table VII. gives a series of representative Brinell hardness numbers for the commonest aluminium casting alloys, based on the 500 kgs. load and a time-limit of 30 seconds. The time-limit is specified because with certain of the softer alloys it is found that the Brinell hardness depends to some extent upon the time during which the specimen is subjected to the load,

and in order to obtain strictly comparable results the time-factor should be constant. The hardness numbers given in the table represent average values of a large number of castings made in chill moulds. With certain alloys the difference in the hardness values for chill and sand-cast specimens is not very large, although this may be due to the fact that such differences are comparable in magnitude with the differences in hardness observed on different specimens cast in the same manner. There appears to be no direct relation between the Brinell hardness number and either the tensile strength or the elongation of aluminium alloys.

In the table, as in subsequent paragraphs in this treatise, the aluminium alloys are referred to in terms of the content of the hardening constituent. Thus, in referring to an 8 per cent. copper alloy, for example, it is understood that the alloy is made up of 8 per cent. of copper plus 92 per cent. of aluminium with normal impurities.

Standard Alloys.

Aluminium alloys readily with the majority of the common metals and a large proportion of the infinite number of possible combinations would be of practical value in the foundry. This very facility for alloying was, in the early days of the aluminium industry, a hindrance to development rather than an assistance, for every different foundryman devised his own particular mixture for which exaggerated claims were often made. As a result, " aluminium " castings were often of very doubtful composition, especially as many of the alloys used were produced by accident or by haphazard experiment, often with a total disregard of elementary metallurgical principles. Thus, alloys have been patented containing small proportions of half a dozen or more different alloying constituents, while in other cases dangerously high proportions of hardening constituents have been used. Zinc, for example, is cheap, and many of the early " aluminium " castings were made of alloys containing 50 per cent. and upwards of zinc, although a glance

at the constitutional diagram would show such alloys to be definitely unstable. Much distrust of aluminium resulted from the subsequent troubles of the unfortunate users of such alloys, and instances are recorded by Rosenhain * where two "aluminium" castings which had distorted or cracked after some years of use were found, on analysis, to contain 81 per cent. and 54 per cent. of zinc respectively.

It is now recognised that all normal needs of the aluminium foundry can be fulfilled by a very few simple alloys containing 4 per cent. to 12 per cent. of copper, or 10 per cent. to 20 per cent. of zinc, or an intermediate proportion of both copper and zinc. Much work directed towards the standardisation of aluminium casting alloys and the evolution of special alloys for particular purposes was carried out during the war under the *ægis* of the British Advisory Committee for Aeronautics, and certain specifications were issued which, after subsequent stages of revision, have now been issued by the British Engineering Standards Association. The main provisions of these specifications are summarised in Table VIII., which contains, besides the minimum physical properties required by the specification, a set of representative figures indicating normal average attainments. Possibly 95 per cent. of all the aluminium castings made in this country at the present time are made in one or other of these alloys.

Zinc Alloys.

Zinc will alloy with aluminium in almost all proportions, but in practice 25 per cent. represents the maximum percentage which can usefully be added, and most often the percentage used will lie between 10 per cent. and 20 per cent. The variation in physical properties with variation in zinc content is indicated by the chart (Fig. 9) which is based on results obtained by Rosenhain and Archbutt.†

* "Some Cases of Failure in Aluminium Alloys," *Inst. Met.*, 1922, No. 1, Vol XXVII., p. 219.

† Tenth Report to the Alloys Research Committee, 1912.

It will be observed that high values of tensile strength are obtainable, and the addition of 15 per cent. of zinc more than doubles the strength of the pure metal while increasing the specific gravity by only 10 per cent.

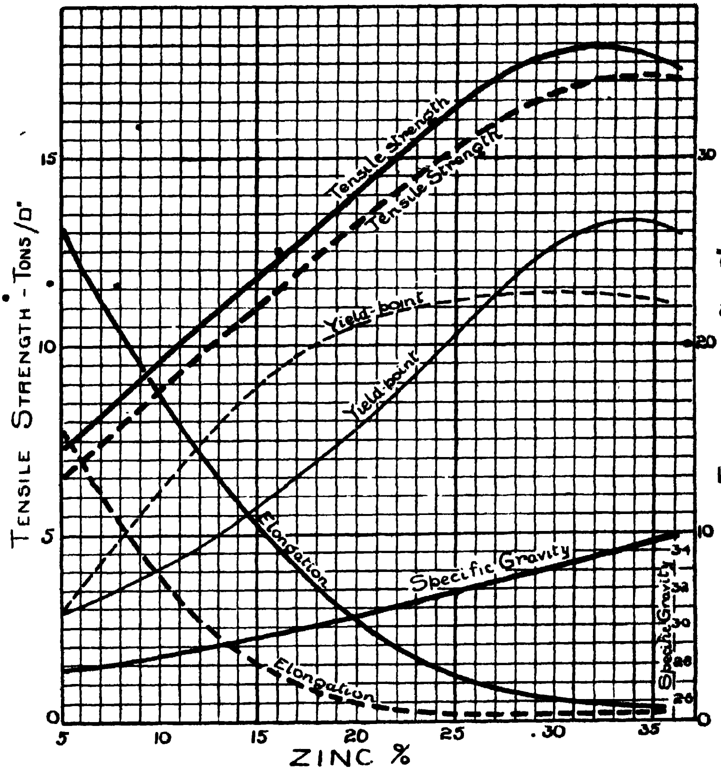

FIG. 9.—Physical properties of the aluminium-zinc alloys in cast form. Dotted curves are for sand-cast specimens; full curves for chill-cast specimens.

The simple zinc alloys are still in some quarters regarded with distrust, but provided that the zinc used is pure, and that the percentage added does not exceed 25 per cent., neither abnormal

corrosion nor distortion will be experienced. These alloys are, in fact, thoroughly reliable in service, and being cheap, tough, and easily machined, had, at one time, a very wide popularity. They suffer from the defect, however, that at elevated temperatures they lose a large proportion of their strength, and a rise of temperature of only 100° C. results in a weakening to the extent of between 40 per cent. and 50 per cent. for alloys containing up to 15 per cent. of zinc. These alloys, therefore, would not be satisfactory for automobile pistons or for any

TABLE VIII.

THE B.E.S.A. CASTING ALLOYS.

Specification No.	Specified Composition.	Minimum Tensile Properties.		Average Tensile Properties.	
		Strength, Tons per sq. in.	Per Cent. Elong. in 2 ins.	Strength, Tons per sq. ins.	Per Cent. Elong. in 2 ins.
3L11	Copper, 6 to 8% Tin, up to 1% Aluminium, Remainder.	9	3	11 to 13	4 to 6
2L8	Copper, 11 to 13% Aluminium, Remainder.	9	Nil.	11 to 12	1 to 2
2L5	Zinc, 12·5 to 14·5% Copper, 2·5 to 3% Aluminium, Remainder.	11	3	14 to 16	6 to 10
L24	Copper, 3·5 to 4·5 Nickel, 1·8 ,, 2·3 Magnesium, 1·2 ,, 1·7 Aluminium, Remainder.	*As Cast.* 11 *Heat-treated.* (No specification yet issued.)	*As Cast.* Nil.	*As Cast.* 11 to 13 *Heat-treated.* 17 to 22	*As Cast.* 1 to 2 *Heat-treated.* 3 to 6

other purpose where they might be subjected to heating. Moreover, this same disadvantage causes considerable difficulty in the process of casting, for immediately after the metal has set in the mould and is still close to its melting-point it is extremely fragile and is liable to crack owing to contraction strains.

A very great improvement as regards this hot shortness is obtained by substituting 2 or 3 per cent. of copper for part of the Zinc, and the L5 composition (Table VIII.) is a typical

alloy of this class, which, while retaining the beneficial characteristics of the zinc alloys, is easier to deal with in the foundry. This alloy has been used in this country for more than twenty years for a very vast range of castings such as crank-cases and gear boxes for automobiles, and it has demonstrated its ability to operate with complete satisfaction for long periods, even for parts subjected to considerable stress.

A somewhat smaller percentage of zinc provides a lower tensile strength but an increased elongation, and an alternative to the L5 is one containing 3 per cent. of copper with 8 per cent. of zinc. This has a tensile strength of 9 to 11 tons per sq. in., with the unusually high elongation of 10 per cent. (chill cast).

Copper Alloys.

The alloys of copper with aluminium may be divided into three groups: (1) those containing up to 12 per cent. of aluminium, which are known under the general term of aluminium bronze; (2) those at the other end of the series containing up to 12 per cent. of copper; and (3) the intermediate compositions. Of these three groups the last is of no practical value, the alloys being hard and so extremely brittle that they can be powdered by hammering. The first group covers an extremely valuable series of alloys which, owing to their high tensile strength and corrosion-resisting properties, have a wide use for ships' propellers, gun mountings, etc. The percentage of aluminium included is, however, so small that castings of these alloys are outside the scope of this treatise, and our attention will be devoted to the group of alloys containing up to 12 per cent. of copper.

The general physical properties are indicated in Fig. 10 (based on tests by Carpenter and Edwards, and others), and it will be observed that the strength rises rapidly with the copper content up to about 8 to 9 per cent., higher percentages producing little corresponding increase in tensile strength and causing a diminution in the percentage elongation. The

alloy containing 8 per cent. of copper, under the designation of "No. 12 alloy," has been used for very many years in America for castings of all descriptions, whether sand cast or die cast,

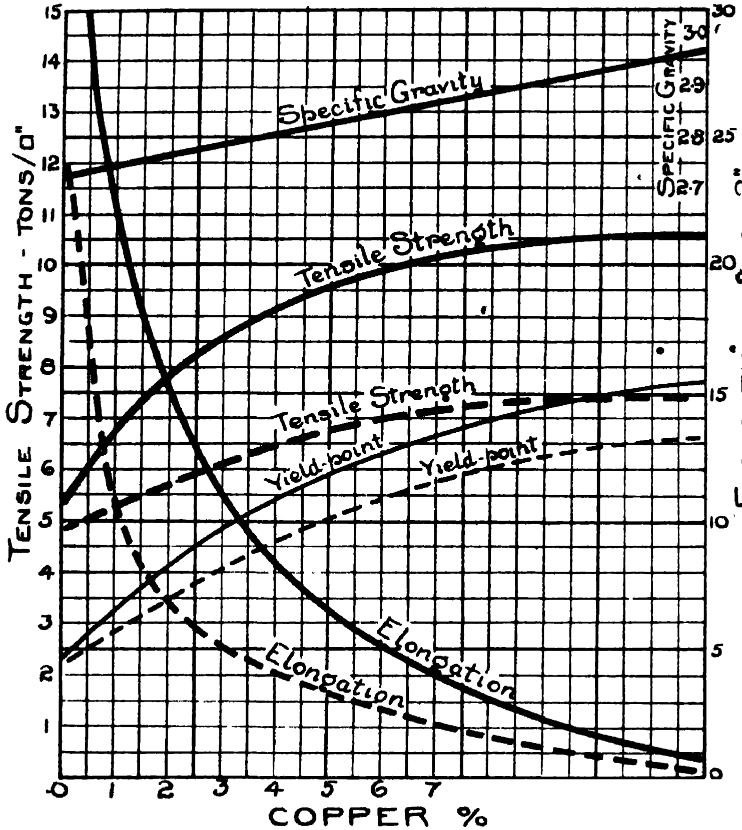

FIG. 10. Physical properties of the aluminium copper alloys in cast form. Dotted curves are for sand-cast specimens; full curves for chill-cast specimens.

whether for important highly-stressed engineering components or for insignificant domestic details. The "No. 12 alloy" is very similar to the 3L11 alloy (Table VIII.), and chiefly differs from the specification in that the latter permits the use of

1 per cent. of tin if desired. It may be remarked that the use of the tin addition was probably included in the earliest editions of the L11 specification on the assumption that it had some effect upon the shrinkage of the metal in the mould during casting, but there seems to be little practical justification for this, and at the present time the tin is usually omitted.

While the use of higher percentages of copper does not provide a superior strength, the L8 mixture, containing 12 per cent. of copper, has useful properties for certain special purposes. This alloy is considerably harder than the 8 per cent. mixture (Table VII.), and has rather better machining properties. Though its strength falls off with increase in temperature, its strength at 200° C. is in the neighbourhood of 7 tons per sq. in.,

TABLE IX.

TENSILE STRENGTH OF ALUMINIUM ALLOYS AT HIGH TEMPERATURES (N.P.L. AND OTHERS).

Composition.	Tensile Strength, Tons per sq. in.		
	20° C.	250° C.	350° C.
13½ Zn, 2½ Cu (L5) . .	13·5	4·2	1·5
12 Cu (L8)	9·8	6·7	4·5
12 Cu, 2 Ni	11·6	10·0	5·3
14 Cu, 1 Mn	9·0	10·0	6·5
4 Cu, 2 Ni, 1½ Mg (Y-alloy)	13·7	12·0	4·6
12 Si (modified) . . .	12·5	9·5	3·2

and it is therefore suitable for automobile pistons. Its lack of ductility at normal temperature would necessarily restrict its use to those applications where unyielding rigidity is not disadvantageous. The L8 composition is not readily handled in the foundry, and unless special care is taken, porosity and hair cracks are apt to occur in the castings.

Another alloy at one time used for pistons contains 14 per cent. of copper with 1 per cent. of manganese. Manganese has the remarkable property of providing an increase in tensile strength with an increase of temperature of 250° C., as is indicated in Table IX. At the same time, however, the addition of

manganese greatly reduces the elongation and, more important still for a piston alloy, the thermal conductivity is diminished. For these reasons, together with the fact that the production of sound castings in this alloy is a matter of considerable difficulty, the mixture is not now used.

Silicon Alloys.

While the bulk of the world's output of aluminium castings is, at the present time, made in zinc or copper alloys, and these alloys have proved their worth by long years of service, comparatively recent developments have re-awakened interest in alloys containing up to 15 per cent. of silicon. It is possible that silicon alloys of aluminium were the first alloys of the metal to be produced in the beginning of the aluminium industry, but the strength and ductility of such alloys showed to no advantage in comparison with those of copper or zinc. For example, the alloy made by melting together 5 per cent. of silicon with 95 per cent. of aluminium would have a tensile strength of about 8 tons per sq. in. and an elongation of 4 to 5 per cent. on 2 inches which would be somewhat inferior to the properties of a 5 per cent. copper alloy. The addition of further quantities of silicon produces little increase to the strength, but a greatly reduced elongation, and a 13 per cent. alloy, for example, would have a tensile strength of little more than 9 tons per sq. in., with an elongation of 1 to 2 per cent. In view of these results, the silicon alloys were accorded little attention, although it had been observed that silicon alloys produced in the electric furnace at the time of the manufacture of aluminium itself had very different properties from those of alloys obtained by melting together the two ingredients. An early investigator of the problem was Dr. Aladar Pacz who, in 1920, patented a method of converting or "modifying" the "normal" alloy obtained by simple fusion, into the more satisfactory type obtained from the electric furnace. His work was quickly followed by announcements of the results of other workers in the same field, and the phenomena involved have now been thoroughly investigated.

Micrographic examination of a 10 per cent. alloy of the "normal" type shows that silicon is present in the form of large crystals, whereas in the "modified" structure the metal is dispersed as a fine constituent throughout the entire mass. This dispersal is accompanied, as would be expected, by a vast improvement in the ductility as well as by a substantial increase in strength.

The improvement in physical properties is indicated by the following test figures * obtained on alloy specimens, containing, approximately, 11 per cent. of silicon, and cast in chill moulds:—

Condition.	Tensile Strength, Tons per sq. in.	Elas. Limit, Tons per sq. in.	Per Cent. Elong on 2 ins.	Per Cent. Reduction of Area.	Brinell Hardness, 20 kgs., 2 mm. ball.
Normal .	10·26	4·72	3·1	2·8	61
Modified	15·04	—	17·2	21·1	65

Silicon alloys used in the "modified" form usually contain 10 to 12 per cent. of silicon, but the variation of properties with other percentages of silicon are indicated in Fig. 11, which is based on tests by Stockdale and Wilkinson.†

The modifying process is carried out on the molten metal just prior to pouring into the moulds, and it consists of merely adding to the metal a "flux" or modifying agent. In the process of Dr. Pacz the flux consists of alkali fluorides (sodium fluoride, for example), which are stirred into the metal at a temperature of about 900° C. In another process the alkali metals themselves, sodium and potassium, are used, while Dr. A. G. C. Gwyer has shown that the effect is obtainable by many other substitutes, such as caustic soda, the alkaline earth metals, calcium and barium, salts of these metals (the

* *Journ. Inst. Met.*, Vol. XXXVI., 1926, No. 2, pp. 318 and 323.
† *Ibid.*, p. 315.

peroxides, for example), and by metallic antimony or magnesium. Indeed, it is possible that the modified structure could be obtainable solely by extremely rapid cooling of the casting without any fluxing agent at all, for it is definitely established that the thoroughness of modification is enhanced if the metal

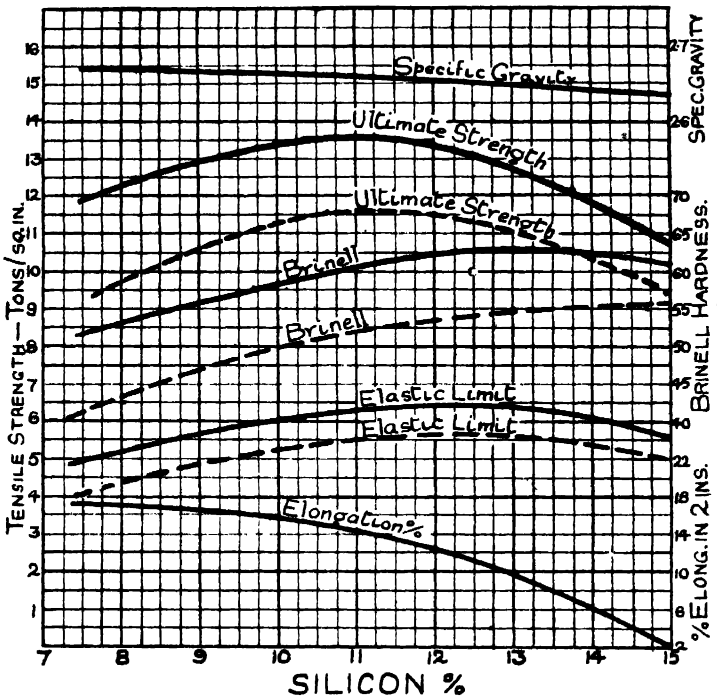

FIG. 11.—Physical properties of the aluminium-silicon alloys in the cast "modified" form. Dotted curves are for sand-cast specimens; full curves for chill-cast specimens.

is cast in chill moulds, and wherever possible chill moulds are used in place of sand moulds.

The explanation for the modifying action put forward by Gwyer and Phillips * is that in the molten state the alloy consists of a true solution of silicon in aluminium, but that below a

* *Journ. Inst. Met.*, Vol. XXXVI., 1926, No. 2, p. 283.

certain temperature the molecules become associated in groups of colloidal particles. At the ordinary rates of solidification the colloidal particles are allowed sufficient time to coalesce into aggregates of microscopic dimensions, but with extremely rapid rates of solidification the constituents have no time to segregate, and the dispersed structure of the "modified" alloy results. The rate of cooling necessary for this is too high to be attained in normal foundry practice, and the function of the modifying agent is to prevent the agglomeration of the colloidal particles.

The metal should not be cast immediately after treatment, so as to give time for all excess of sodium to be burnt out, but it should not be kept too long molten or it may revert into the "normal" condition again. The length of time necessary to give the best results depends upon the quantity of modifier used and also, to some extent, upon the quantity of silicon contained in the alloy. Depending upon the conditions the best time may vary from 5 minutes to over 20 minutes.

It is important that silicon alloys should be made up with aluminium containing as small a proportion of iron as possible, since iron is particularly deleterious as regards the ductility of the metal. A value of 0·7 per cent. to 0·8 per cent. of iron is suggested as the maximum permissible for good results, though an even smaller value is desirable for important work.

Apart from the good mechanical qualities of the modified alloys, silicon alloys in general have additional advantages which may be summarised as follows :—

1. The specific gravity of silicon is 2·4 as compared with 2·7 for pure aluminium, and the silicon alloys are therefore lighter than the parent metal, the specific gravity varying as indicated in Fig. 11, according to the silicon content.

2. Silicon alloys are not hot-short. The shrinkage on solidification is low, and the strength and elongation are high at the solidification temperature, so that the metal is particularly easy to deal with in the foundry and difficult castings can readily be obtained free from cracks, porosity and similar

foundry defects. This property is, perhaps, the most important of all, since it enables silicon alloys to be used in circumstances where other aluminium alloys would be unsuccessful or only successful with great precautions. A typical instance is shown in Fig. 12, where a thin-walled aluminium cylinder has been cast around a rigid steel barrel without cracking.

3. Silicon alloys have exceptionally good corrosion-resisting properties in which respect they are superior, in some instances, to pure aluminium. This particularly applies to the conditions of ship-board use, and silicon alloy castings are so little affected by sea water as to be described as incorrodible.

In view of these properties, silicon alloys are likely to have a wide application in the future, and apart from modification, which is a patented process, simple alloys containing up to about 5 per cent. of silicon are used for sand castings in the unmodified condition. The modified alloys are supplied under such trade names as "Wilmil," "Alpax," "Silumin," etc.

One objection to the silicon alloys is the fact that owing to their softness they are not so easily machined as other alloys, and in addition the elastic limit is so low that the casting may be permanently stretched by loads which are well below the ultimate value. In many applications this would prevent advantage being taken of the high strength, and interest is therefore attached to the effects of replacing part of the silicon with some other material. It is found that ternary alloys of copper, silicon and aluminium retain much of the excellent casting ability of the simple silicon alloys while, at the same time, being harder and rather better as regards machining qualities. A typical composition contains 3 per cent. of silicon, with 4 per cent. of copper, the remainder being aluminium, and alloys of this kind have been adopted by the United States Air Service for difficult castings. The alloy is used without any attempt at modification, and in the sand-cast form has a strength of about 8 to 9 tons per sq. in., with an elongation of about 2 per cent. to 4 per cent. on 2 inches. Though the strength is low, this is considered of small importance because the elastic

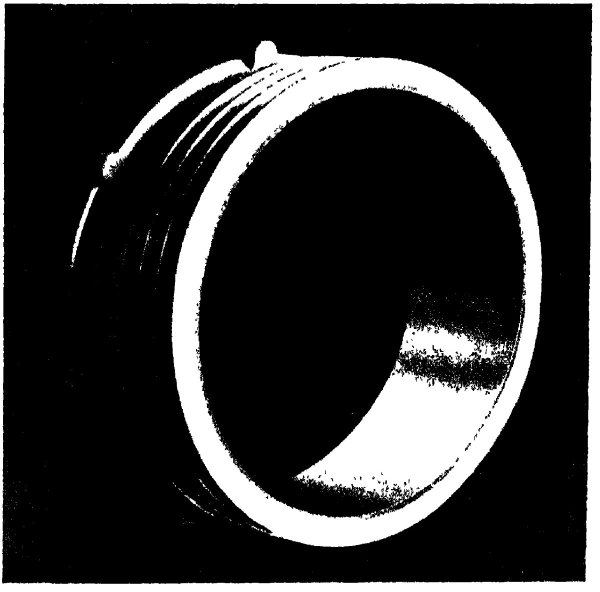

FIG. 12.—Brake drum cast in aluminium-silicon alloy with steel liner cast integral. (Wm. Mills, Ltd., Birmingham.)

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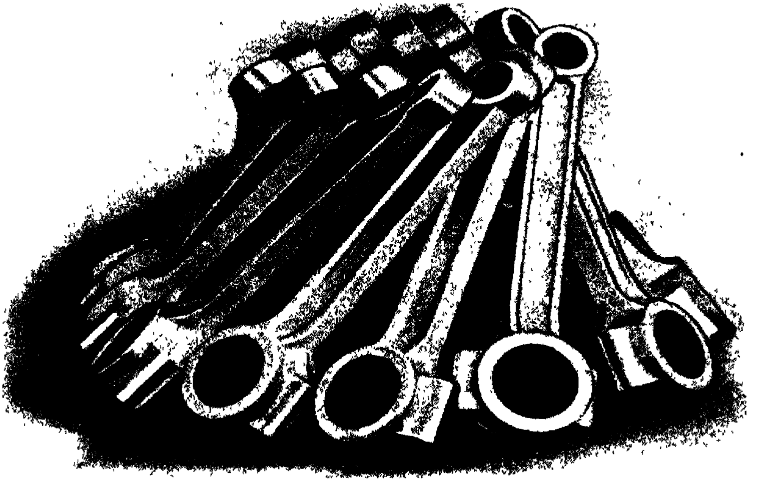

FIG. 13.—Cast connecting rods in heat treated Y-alloy. (Wm. Mills, Ltd., Birmingham.)

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limit occurs at a high proportion of the breaking load, and from the point of view of ability to withstand load without deformation this alloy has equal value with the modified 12 per cent. silicon alloy without necessitating any modification process.

Heat-Treated Castings.

The very profound effect of heat treatment in the case of certain aluminium alloys used in the rolled or forged condition suggests that if similar results are obtainable with castings it might be possible to manufacture such highly stressed parts as connecting rods in the aluminium foundry, and by subsequent heat treatment obtain the same strength as forged steel. Now an essential feature of the mechanism whereby the physical improvement is attained in heat treatment is a ready interdiffusion of the components of the alloy in the solid state. In a forging, or in any worked material, this diffusion is assisted by the close packing of the crystals under the deformation, but in a casting the structure is altogether looser, and diffusion takes longer. A casting is, therefore, inherently less susceptible to heat treatment, and this is emphasised still further if the casting should be slightly unsound. In a porous casting free diffusion is checked by the minute pores, and in severe cases may be inhibited entirely. In order, therefore, that a casting should exhibit the maximum response to heat treatment, it should be cast in a chill mould to obtain the maximum compactness of structure, and it should be entirely free from defects.

Unfortunately, those alloys which, in the sheet form, are most susceptible to heat treatment are among the worst possible alloys for ready founding. Duralumin, for example, is exceedingly hot-short, and duralumin castings are apt to be porous and to contain fine hair cracks. Test specimens carefully poured in a sand mould may attain a tensile strength of 10 to 11 tons per sq. in., but on submitting these to the normal heat treatment and ageing, very little improvement is obtainable

It has been suggested * that the inter-diffusion of the components may be still further impeded by internal oxidisation in the pores during the ageing period, produced by the furnace gases and quenching water, and on specimens heat-treated in conditions specially designed to prevent such corrosion a strength of 16½ tons per sq. in. with 1·7 per cent. elongation has been obtained. Even this result, however, is by no means comparable with the improvement obtained on heat-treating the metal in the sheet form, and better results are obtained with simpler alloys which are more easily cast.

Simple copper alloys, for example, when heat-treated in the cast form attain almost the same percentage improvement in strength as has already been noted for the same alloys in sheet form. Rosenhain and Archbutt † record the following figures for a simple aluminium-copper alloy containing 4·5 per cent. of copper in the form of 1-inch diameter chill-cast test bars.

	Tensile Strength, Tons per sq. in.	Per Cent. Elongation on 2 ins.
As cast	9·6	11·0
After annealing at 500° C.	15·0	15·0
After annealing, quenching and ageing	17·3	25·0

Still more striking results are obtainable with the Y-alloy, containing 4 per cent. of copper, 2 per cent. of nickel, 1½ per cent. of magnesium and the rest aluminium, the general properties of which, in the rolled form, we have already remarked upon. When cast in a chill mould the tensile strength of this alloy is of the order of 12½ tons per sq. in. with 1 per cent. elongation in 2 inches, but on heating for six hours at 525° C. in a nitrate bath, followed by quenching in boiling water and ageing for five days at air temperature, the strength may rise

to 21 tons per sq. in. with an elongation of 6 per cent. With sand-cast specimens the corresponding figures are 11½ tons per sq. in., as cast, and 17 tons per sq. in. after heat treatment.

This alloy is remarkably good, both as regards heat conductivity and strength at high temperatures, and it is satisfactory for machining. Though much more readily cast than duralumin, it is, however, by no means simple to deal with in the foundry. Owing to the highly oxidisable nature of magnesium the initial mixing of the alloy requires special care or the composition of the alloy as cast may be substantially different from that which the founder intended.

More difficult to combat is the strong tendency for the metal to absorb gas, which is liberated at the moment of solidifying, and results in the production of a vast number of pin-holes throughout the casting. The presence of these pin-holes does not appear materially to affect the strength of the metal as cast, but they will restrict the sensitivity to heat treatment. They may occur on the surface as a myriad of pock-marks which show up on machining, and they are particularly objectionable in castings which are intended to withstand hydraulic pressure, since they may permit sweating. Their formation is largely eliminated by pouring at the lowest possible temperature and by using chill moulds so that the metal solidifies rapidly.

The absence of pin-holes with a rapidly-cooled casting is due to the fact that the gas occluded has no time to come out of the solution as minute bubbles and is retained in solution. It logically follows that sound castings could also be obtained if the metal were allowed to solidify so slowly that the gas bubbles have time to rise to the surface and leave the metal completely free. Experiments in this direction by Archbutt * have shown that this is the case, and he found that if, after mixing, the alloy is allowed to cool very slowly in a crucible until it solidifies and is then remelted, the castings obtained from the remelted alloy, even in sand moulds, are largely free from pin-holes.

Other Alloys.

Nickel.—Simple aluminium-nickel alloys containing up to about 5 per cent. of nickel are used to some small extent, but these alloys appear to offer no advantages over simple copper alloys, except, possibly, as regards resistance to corrosion, and also as regards electrical conductivity. More usually nickel is used as a constituent of more complex alloys since, in combination with other alloying constituents, it appears to be decidedly beneficial. The addition of 2 per cent. of nickel, for example, to the 8 per cent. copper alloy raises the tensile strength to about the same as that for a 10 per cent. copper alloy, but causes no decrease in the elongation.

Magnesium.—Magnesium has the advantage that it is lighter than aluminium (specific gravity = 1·74), so that the magnesium alloys have the lowest specific gravity of all those commonly used. Aluminium-magnesium alloys, in practice, contain either over 90 per cent. of magnesium or they contain not more than 5 or 6 per cent. of magnesium. The latter attain a tensile strength of about 10 tons per sq. in. (chill cast), with 3 to 4 per cent. elongation, but owing to foundry difficulties and the high cost of magnesium the use of these alloys is not extensive. Magnesium combines with the normal silicon content of aluminium to form an extremely hard compound, so that the hardening effect of small percentages of magnesium is very marked. It is possibly due to this that the castings are capable of being finished with an unusually high polish.

Magnesium enters into the composition of several important complex alloys, for example, duralumin and Y-alloy, and forms a useful series of ternary alloys with copper and aluminium, a typical example of which contains 2 per cent. magnesium with 2 per cent. of copper.

The interesting fact that a small quantity of magnesium, even only 0·5 per cent., conveys the property of hardening on quenching is the main reason for the use of magnesium in these combinations.

Manganese.—Manganese forms with aluminium a hard, dense, brittle compound, which causes a very rapid reduction in the elongation without any abnormal addition to the tensile strength. For this reason simple binary alloys of aluminium and manganese are not used to any material extent, but manganese has been employed as an addition to aluminium-copper alloys, the amount employed being not more than 1 to 2 per cent. The replacement of 1 per cent. of copper in a 4 per cent. aluminium-copper alloy by 1 per cent. of manganese will produce an increase in tensile strength of 2 to 3 tons per sq. in. with no reduction in elongation, or even with an improvement in elongation. We have already noted the ability of aluminium alloys containing manganese to improve in tensile strength with increase in temperature, and another of their outstanding properties is an exceptionally good resistance to sea-water corrosion.

On the other hand, manganese alloys are difficult to handle in the foundry, since they are apt to have a large contraction on solidification. Moreover, the strength of the casting is very susceptible to the influence of the temperature of pouring, and great care must be taken to keep this as low as possible.

Iron.—Iron occurs occasionally in aluminium alloys to the extent of 1 per cent. or more either by design, or by accident due to absorption of iron from the melting-pots. There would, however, appear to be little justification for introducing iron deliberately, for, although an increase in tensile strength is obtained with a reduction in elongation, the same results would be obtainable by an addition of an equal percentage of copper without the disadvantages accompanying the use of iron. The main disadvantage is a distinctly increased tendency towards porosity, and it has been stated that this is due to the formation of an iron-aluminium compound which crystallises out first, as the alloy cools, in the form of a skeleton of needle crystals within which the remaining liquid solidifies. Action of this kind would provide an explanation of why the addition of iron is said to reduce the shrinkage. It will be

evident that while shrinkage may be reduced by the early formation of the iron-aluminium skeleton, the shrinkage does, in fact, occur within the skeleton and results in porosity.

Tin.—The addition of 1 per cent. of tin to certain of the simple aluminium alloys, notably copper alloys, was at one time advocated as reducing the crystallisation shrinkage and the tendency for pin-holes. The general opinion now is that if such effects occur at all they do not occur in a sufficiently marked degree to warrant the use of this relatively costly material, and tin is now rarely used, especially as tin oxide, readily formed, is highly detrimental. In general, 1 per cent. of tin is said to have little effect on the tensile strength of an alloy, but to improve the ductility. Tin is also said to add to the polishing ability of the alloys.

CHAPTER III.

MELTING AND MIXING.

Melting-point.

The melting-point of the purest aluminium normally obtainable (99·6 per cent.) is 658·7° C., and the metal of ordinary purity as used in general industrial practice will melt at about 658° C. In accordance with the general metallurgical rule, the melting-point of light aluminium alloys is lower than that of the pure metal, even though the added constituents are of higher melting-point, and a selection of melting-points will be found in Table X. In this table the figures given are those

TABLE X.

MELTING-POINTS.

Composition.	Melting-point, °C.	Composition.	Melting-point, °C.
Pure Metals—		*Light Alloys—*	
Aluminium .	658	4 Cu . . .	643
Copper . .	1083	8 Cu . . .	630
Magnesium .	652	12 Cu . .	622
Zinc . . .	419	10 Zn . .	640
Nickel . .	1452	20 Zn . .	620
Manganese .	1230	13 Zn, 2½ Cu .	615
Iron . . .	1530	10 Zn, 3 Cu . .	620
Silicon . .	1420	20 Zn, 3 Cu .	600
Tin . . .	232	3 Ni . . .	645
		5 Ni . . .	639
Mixing Alloys—		5 Si . . .	628
50 Cu, 50 Al .	586	11½ Si . .	578
30 Cu, 70 Al .	555	5 Mg . .	630
20 Cu, 10 Fe, 70 Al	865	10 Mg . .	605
		2 Ni, 2 Cu . .	646
		2 Ni, 4 Cu . .	638
		Y-alloy . .	620

at which the metal is completely liquid. With pure metals and with certain of the alloys, melting occurs at one definite temperature, but with the majority of aluminium alloys the metal passes through a pasty stage where it is neither solid nor completely liquid, and this pasty stage may occupy a range of as much as 100° C. The 8 per cent. copper alloy, for example, begins to melt at 545° C. but is not completely liquid until 630° C. On the other hand, the 11½ per cent. silicon alloy begins to melt and becomes completely molten at one definite temperature, 578° C. The reason for this difference lies in the constitution of the alloy, and the majority of alloys contain molecular combinations of the constituent metals which melt at different temperatures, so that in the pasty stage certain of the ingredients are liquid while others are still solid.

Overheating.

In the melting of aluminium or aluminium alloys it is desirable that the temperature of the metal should not be allowed to rise very greatly above the melting-point. For casting purposes it is necessary that the metal be super-heated to some extent in order to ensure that it shall completely fill the mould before it solidifies, and the minimum pouring temperature permissible will vary according to the nature of the mould. If the casting has thin sections at remote parts of the mould, it would be necessary to pour at a higher temperature than if the casting were a compact mass; but in all cases the pouring temperature should be kept as low as practicable, and it would be only in rare cases that the temperature must be raised to more than 100° C. above the melting-point.

The importance of this can readily be shown experimentally. If a series of test bars be cast in similar moulds with metal at different temperatures, it will usually be found that bars cast at the lowest temperature are superior both in mechanical properties and in soundness. Figures obtained in this way with the 3L11 alloy cast in sand moulds are given below, and strikingly demonstrate the desirability of low temperature pouring.

Pouring Temperature.	Ultimate Strength.
650° C.	9·1 tons/sq. in.
700° C.	8·6 ,, ,,
750° C.	8·2 ,, ,,
800° C.	7·9 ,, ,,
850° C.	7·3 ,, ,,

Apart from the effect of pouring at a high temperature on the contraction in the mould and the rate of solidification, both of which have some bearing on the results obtained, the high temperature increases the risk of oxidation and of gas absorption. Aluminium is readily oxidised, so that in the molten state it quickly becomes covered with a skin of oxide on the surface. The oxide is actually of somewhat higher specific gravity than the molten metal, so that, if stirred in, there is little tendency for it to rise to the top of the melt. Normally, however, it forms a tough and coherent skin on the surface, and the viscosity of the metal is such that, if the melting is carried on quietly, there is little risk of oxide contamination.

If the temperature is raised unduly the rate of oxidation increases, so that the risk of oxide inclusions becomes more serious.

The absorption of gases—oxygen, carbon dioxide, hydrogen, and so on—also proceeds more rapidly at higher temperatures than at low, and since the dissolved gases will largely be rejected when the metal cools, castings made from overheated metal may contain a mass of pin-holes due to minute bubbles of occluded gas.

It will be evident that the lower the temperature of pouring the less will be the risk of failure due to these causes, and it will be equally evident that overheating will not necessarily ruin the metal permanently. If metal which has accidentally been overheated is allowed to solidify slowly and undisturbed in a pot with a cover and then remelted, the dissolved gases will have time to come away, and in rising will tend to carry up with them particles of oxide which may be dispersed in the metal. If the crust of oxide and dross is then carefully skimmed off, and the metal poured, the casting should be none the worse for the overheating. It is quite possible, in fact, to remelt a

casting which has been ruined by pouring at too high a temperature, and to recast with the same metal under proper conditions and so obtain perfectly satisfactory results.

Furnaces.

The type of furnace and the nature of the fuel employed in melting aluminium are governed very largely by the rate of output of molten metal required. Economic considerations suggest the use of large units, for the amount of fuel required for melting any particular quantity will, in general, be less if the quantity is melted in bulk rather than in, say, two furnaces of half the capacity each. In applying such a rule to particular cases, however, consideration must be given to the strong disadvantage of allowing aluminium to remain long in the molten state, and the metal should be dealt with in such quantities that it can be drawn off and cast as soon as it is melted. For this reason in most foundries the metal is melted in quantities varying from 100 to 500 lb. per charge. Although this quantity seems small, it must be remembered that 100 lb. of aluminium occupies as much space as 330 lb. of brass, and, moreover, requires almost as much heat to melt it.

Furnaces may be classified into two types, those in which the metal is melted in a closed vessel, such as a crucible, in such a way that it is protected from the flames, and those in which the melting is effected by radiation from a white-hot furnace lining, assisted, sometimes, by direct contact with flames or flue gas.

The crucible type of furnace is necessarily limited in size, and is costly in fuel and slow in melting, for the heat is conveyed to the metal by conduction through the crucible walls. Crucibles themselves are costly and have only a short life, whereas the lining of a reverberatory or open flame furnace is capable of several years' continuous use before renewal becomes necessary.

On the other hand, the use of an open flame with a metal so readily oxidised as aluminium at once suggests the possi-

bility of abnormally high dross loss. In actual practice, however, the amount of oxidation occurring in an open flame furnace does not appear to be substantially greater than in a crucible furnace, and the reason probably lies in the great rapidity of melting. Obviously, this point needs attention, and it is conceivable that with unintelligent handling the open flame furnace provides a greater possibility of "burning" the metal. This disadvantage, in the experience of many founders, is greatly out-weighed by its advantages, and the open flame type, in units of all sizes, is being widely adopted to supersede the older crucible type.

Pit Type Furnaces.

The pit type crucible furnace is still employed in the majority of aluminium foundries in spite of its low efficiency, because, for the most part, the founding of aluminium has developed out of brass foundry practice in which the pit type furnace has been standard from the earliest ages. The pit type furnace is, in fact, little different in essentials from the furnace of the pre-historic bronze workers whose melting apparatus was a hole in the ground stuffed with fuel and fed by air tunnels. The modern prototype consists of a pit in the foundry floor some 3 or 4 feet deep, which is lined with fire-brick. Into this the crucible is placed, packed round with red-hot coke, and the temperature control is exercised by a damper in the flue. The furnace is effective, for intense degrees of heat are obtainable, and though the fuel consumption is high, it is possible that careful attention to design would lead to much greater efficiency than is normally attained.

In this connection Fig. 14, which is reproduced from a paper by Mr. L. C. Harvey,* illustrates a well-thought-out design, the principal features of which are as follows :—

The furnace is provided with an inner renewable lining, which is separated from the outer fire-brick lining *b* by means of a heat-insulating air space *s*. Still further heat insulation is

* *Journ. Inst. Met.*, 1917, Vol XVIII., No. 2, p. 213.

provided by lagging the whole outer surface with asbestos held by the sheet iron or expanded metal casing *a*. Covers at *d* and *x* prevent loss of heat vertically, and at the same time

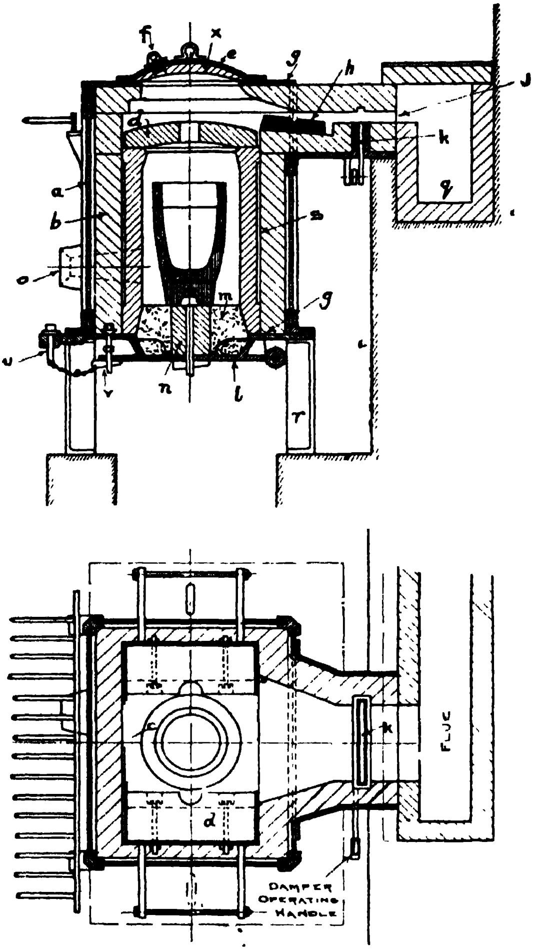


FIG. 14.—Pit type crucible furnace. (L. C. Harvey.)

ensure that the products of combustion are properly drawn off through the flue. The flue itself is so constructed that it contains a pre-heating hearth, where ingots of metal for the next

charge (*h*) can be given a preliminary heating by the hot gases. An efficient damper is provided at *k*.

The bottom of the furnace is in the form of a hinged pan *l* which will collect spilled metal, and this pan is filled with quartz nodules *m* through which any such metal, together with slag, can work to a level below the fuel level. The crucible itself stands on a firm pedestal *n*.

As shown, the furnace is designed for gas firing, a gas burner attachment *o* being provided, but the same design is applicable for coke firing with small modifications.

When designed for coke fuel the usual system is to employ natural draught, but forced draught furnaces are employed to some extent, and have the advantage that the draught is independent of atmospheric conditions and that the rate of heating is quicker while being susceptible to careful control.

Where the output required is such that more than one crucible is required, the furnace is built up with individual chambers for each crucible, with a separate connection to a common flue and chimney. If gas or oil fuel is employed two or three crucibles may be arranged in a common melting chamber with a single burner. If the shape of the melting chamber is properly designed the flame is directed in such a way that all the crucibles are heated equally. With this arrangement it is not possible to charge, stir, or remove any one crucible without temporarily shutting down the others, and if more than three crucibles are employed it is preferable to provide separate melting chambers with separate covers and separate flue outlets and dampers. This does not necessarily involve a separate burner for each melting chamber, and the crucibles may be arranged to sit in a common firing chamber, the upper portions only being separated. With such an arrangement the shutting of the flue of one compartment will enable the cover to be removed and the crucible to be inspected without permitting fumes to escape,—the flames from the burner passing straight across the bottom to the other compartments.

Crucible Tilting Furnaces.

The pit type furnace, in which the crucibles are lifted out bodily for pouring, necessarily involves the melting of aluminium in quantities not exceeding about 100 lb.; for larger quantities the crucibles are apt to be strained or damaged by the tongs. The interests of economy and efficiency point to the desirability of melting in considerably larger quantities, and

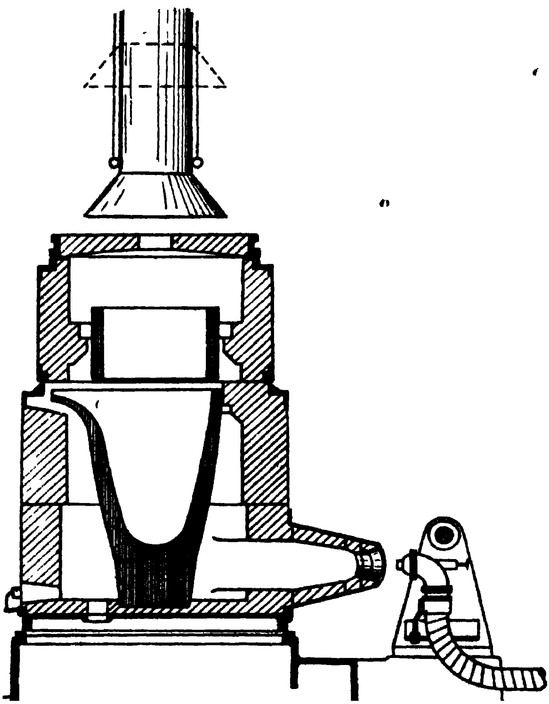


FIG. 15.—Arrangement of crucible tilting furnace for oil burning. (Morgan Crucible Co., Ltd.)

this has led to the introduction of a type of crucible furnace in which the crucible itself is never removed from the furnace and pouring is effected by tilting. A typical furnace of this kind, manufactured by the Morgan Crucible Company, Limited, is shown in Fig. 16, and in the diagrammatic section view, Fig. 15.

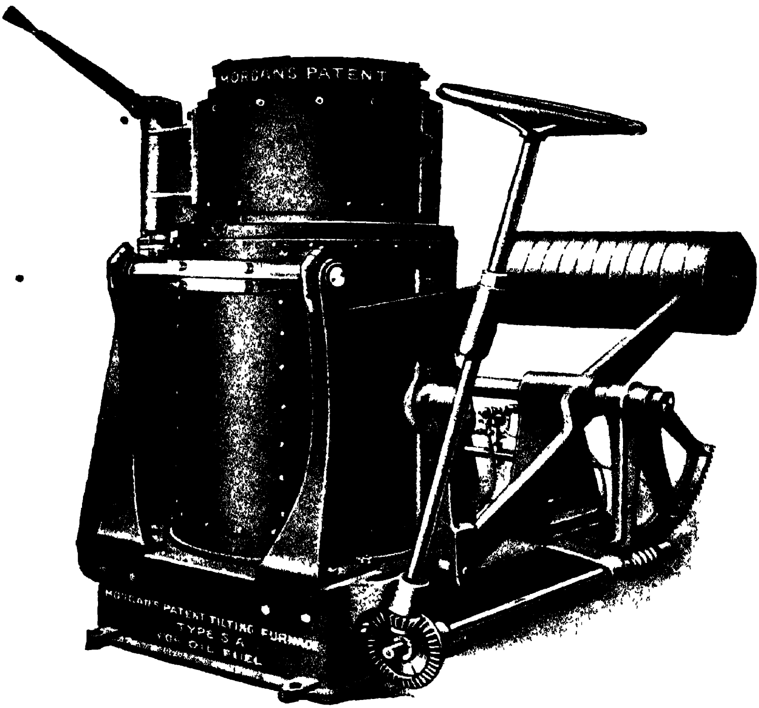


FIG. 16.—Crucible tilting furnace. (Morgan Crucible Co., Ltd.)

[*To face page* 56.

The furnace itself consists of a cylindrical steel casing lined with refractory brick, with a tangentially arranged inlet for the flames of an oil burner at the bottom. In this sits a Salamander crucible of a capacity up to about 350 lb. of aluminium (1000 lb. of brass), and the flames rotate spirally in the concentric space between the crucible and furnace lining, finally escaping through a central hole in the cowl or "pre-heater" section at the top. The gases are carried off to the open air by means of a light telescopic chimney.

The pre-heater section is carried on a side bracket, and so arranged that it can be raised and swung clear of the furnace

TABLE XI.

OPERATING FIGURES FOR MORGAN TILTING FURNACES WHEN MELTING ALUMINIUM. (MORGAN CRUCIBLE CO., LTD.)

Size Furnace.	Wt. of Aluminium per Charge.	Fuel per 100 lbs. Metal Melted.	Time of Melting.		Output per 8-hour day.	
			1st Heat.	Subsequent Heats.	No. of Heats.	Total Melted.
lbs.	lbs.	gals.	mins.	mins.		lbs.
150	50	3.3	40	25	11	550
200/250	80	2·0	45	30	9	720
400/450	150	2·5	55	35	8	1200
600/650	220	2·1	70	45	7	1540
1000	375	2·2	85	60	5·6	2250

prior to pouring. It contains a Salamander ring which, during heating, fits round the top of the crucible and thus encloses and protects from the flue gases any super-charge of metal. The charging of the crucible is effected through the top of the pre-heater section, which is provided with a sliding cover for the purpose.

A particular feature of the design is the mechanism by which the pouring lip of the crucible is maintained at approximately the same position during the tilting, so that the stream of molten metal can easily be directed into, say, a billet mould.

Some operating particulars of furnaces of this type supplied by the makers are given in Table XI.

Reverberatory Furnaces.

For melting aluminium in large bulk, say 1000 lb. or more per charge, the reverberatory furnace ordinarily used for smelting ores is sometimes employed. This furnace, as is well known, consists of a hearth on which the metal is placed, with the fire at one end, separated only by a fire-brick bridge over which the furnace gases pass, sweep over the hearth, and exhaust through a flue at the other end. In order to limit oxidation the hearth itself may partly be roofed over with fire-brick, thus preventing direct contact with the flames until complete combustion has occurred.

Such furnaces are employed only in very special circumstances, of course, since for foundry purposes the metal consumption would not justify melting in such quantities. The reverberatory principle is, however, employed in a form of furnace, of which those shown in Fig. 17 are typical. These furnaces consist of an outer cylindrical shell of steel lined with refractory brick and mounted on rollers so that they can be tilted axially to discharge molten metal from a spout in the barrel circumference. Gas burners are arranged in the upper part of the cylinder and direct their flame across the surface of the metal, raising the temperature of the furnace lining to white heat.

The outstanding feature of these furnaces is the extreme rapidity of melting, combined with low gas consumption, and these points are illustrated by the following figures.

These are taken from the daily records of a Birmingham foundry, and represent a normal day's working. Throughout the day 11 heats were made with 330 lbs. of L5 alloy per charge. For the first heat, starting from cold, the time required was 67 minutes, the gas consumption being 1296 cubic feet or 3·92 cubic feet per lb. of metal melted. For the second heat the time taken was 51 minutes, with a gas consumption of 2·94 cubic feet per lb., and for subsequent heats there was a gradual diminution in these values until at the eleventh heat

the time was 40 minutes, and the gas consumption per lb. was 2·39 cubic feet The total and average results throughout the whole day, including the first as heat, are follows :—

Total weight of metal melted . . .	3630 lbs.
Total time	8 hrs. 34 mins.
Total gas consumption	10,111 cu. ft.
Average time per melt	46 mins.
Average cost of gas (at 3s. 2d. per cu. ft.) .	0·106d. per lb. of metal.

Very many variations of the type shown in Fig. 17 are upon the market, and among those worthy of special mention is the completely rotary type in which the whole furnace is rotated continuously during the melting. The metal is thus heated, not only by radiation, but also by direct contact with the hot furnace lining as it rotates. Melting thus proceeds from both top and bottom of the bath and is, therefore, particularly rapid. The speed of rotation with aluminium is slow, so that there appears to be little difficulty due to the carrying of slag beneath the surface.

Fuel.

While coke still remains the most commonly employed fuel for aluminium melting, and when used in a scientifically designed furnace is economical, the cleanliness and convenience of gas or liquid fuels, together with the facility with which they permit furnace conditions to be controlled, is leading to their adoption in many of the more modern foundries. With these fuels the furnaces can be started up quickly, require no stoking, and no daily clean out. Crucibles last longer, no ashes have to be disposed of, and there is no manual handling of the fuel. With gas no storage space for the fuel is required, and with oil the storage consists of a tank, usually buried beneath the ground surface, which can be located in any odd corner.

Possibly the greatest convenience of these fuels for aluminium melting lies in the readiness with which the temperature of the melt can be controlled. A high temperature is not necessary for melting aluminium, and it is of the greatest convenience to be able to control the temperature within 10 to 20

degrees, but with coke fuel this requires greater care than the ordinary furnace hand can be relied upon to exercise.

With a suitable burner almost any kind of waste oil can be employed for melting, and low-grade oils of suitable quality, such as shale or petroleum residues, are obtainable at a cost of 1½d. to 3d. per gallon. Practically the only requirements for a fuel oil, apart from a reasonable calorific value, are, firstly, a sufficient fluidity to enable it to flow freely through the burner valves, and secondly an absence of excessive water content. If the water content exceeds about 2·5 per cent., the calorific value will be low, and at the same time the products of combustion will have a deleterious effect upon the crucibles.

Oil burners are of two kinds, those working with a high-pressure air blast of from 20 to 25 lb./sq. in., and those working with the comparatively low pressure (20-inch water gauge), provided by a simple fan blower. Greater economy of fuel is obtainable with the high-pressure system because the oil is atomised more thoroughly and better consumption results, but the high-pressure system involves the installation of a somewhat expensive air compressor, with a driving motor rated at from 5 to 10 h.p. per burner, and an air receiver, whereas with the low-pressure system the installation is much less costly and the power absorbed is only in the neighbourhood of 1 to 2 h.p. per burner. For aluminium melting the low-pressure system appears to be the more popular.

Gas fuel of all kinds is employed with various systems of high and low pressure, the choice of which will be dictated by economic reasons rather than by any marked technical superiority of one or the other for the purpose of aluminium melting. Among the most efficient of these systems is that of the Selas Gas and Engineering Co., Ltd., which is adopted with the furnace battery shown in Fig. 17. In this system the furnace burners are supplied with a ready prepared mixture of gas and air in the correct proportions for combustion. The mixing and compressing apparatus is illustrated in Fig. 18, and the operation is as follows :—

FIG. 17.—Battery of gas-fired reverberatory furnaces. (Selas Gas and Engineering Co., Ltd.)

[See page 58.

FIG. 18.—Gas compressor and mixing apparatus for the Selas system.

[To face page 60.

Gas enters the apparatus through a governor which reduces its pressure to atmospheric, and it then passes on to a mixing chamber where it is brought into contact with air drawn in direct from the atmosphere The mixing chamber contains a piston valve which, rising and falling in accordance with the demand of the furnaces, opens and closes gas and air ports in such a way as to maintain a constant pre-determined mixture. The mixture is then drawn into a rotary compressor where its pressure is raised to about 32-inch water gauge, and it is then passed direct to the burners. A pressure governor is provided to maintain the pressure constant, and if the supply of gas exceeds the demand, even momentarily, the pressure governor opens and connects the compressor outlet with the inlet. This causes a back pressure valve to operate, cutting off any further supply of the mixture from the compressor.

The system is, therefore, so designed that the mixture is automatically supplied at a constant pressure and in constant proportions, irrespective of any variation in the gas supply pressure, the atmospheric conditions or the furnace demand.

Crucibles.

The crucibles used for melting aluminium or for transporting molten aluminium from the furnace to the mould, may be of iron, graphite or any of the other materials ordinarily used in foundry practice. Graphite or Salamander crucibles are recommended by many users because it is impossible for the molten metal to absorb any impurities from them, however long the metal may remain in the crucibles, but the cost of such crucibles is very considerably greater than that of iron crucibles and their life is short, while the heat conductivity, though good at first, is apt to fall off rapidly with use. Moreover, the distrust of iron from the point of view of possible contamination does not appear to be well founded, for in a series of experiments carried out on behalf of the German Institute of Metals it was shown that up to a temperature of 750° C. iron is not absorbed by aluminium to any appreciable

extent during periods of exposure up to 24 hours. It is true that at higher temperatures iron dissolves more rapidly in aluminium, but the maximum temperature of melting, except in alloy mixing, should not exceed 800° C., while the normal period of exposure to the iron pots is comparatively short.

It is sometimes argued that while with one melting the amount of iron absorbed may be negligibly low, this must gradually increase, since, in general practice, each melt contains a certain proportion of scrap metal. It can be shown mathematically, however, that the iron content will not increase indefinitely. If the amount of iron absorbed per melt is 0·01 per cent., then after an infinite number of remeltings, in which 50 per cent. of virgin metal is mixed with 50 per cent. scrap, the iron content will not exceed 0·02 per cent., while if, as is more usual, each pot contains only 30 per cent. of scrap the iron content will not exceed 0·015 per cent., however many remeltings are carried out.

The danger of contamination is reduced to completely negligible proportions if the iron pots are given a dressing of some neutral wash. A mixture of 10 lb. of whiting and 6 oz. of water-glass in 5 gals. of water is very satisfactory when applied in a very thin coat, preferably over a preliminary thin wash of one part by volume of graphite in two parts of water. The coatings may be applied to pots which have previously been warmed so that they dry quickly. They should be applied very thinly, otherwise there is a tendency for them to chip off. Periodic renewal is necessary, and the pots should be thoroughly scraped every second day.

The use of the wash should, of course, be applied to all iron ladles, skimmers, etc., used in contact with the metal.

The life of an iron pot varies enormously according to the type of furnace and melting conditions, but in an ordinary coke-fired pit furnace at least 50 melts should be counted upon before the eroding action of the coke and flue gases makes replacement desirable. Considerably longer life is to be expected with gas or oil fuel.

Pyrometers.

In the case of brass or iron an experienced foundryman can judge the correct temperature of the melt by the appearance of the metal, but aluminium melts at a dull red heat and is very considerably over-heated at a light red heat, so that the scope for visual determination of temperature is very limited. Moreover, with aluminium the consequences of over-heating and of pouring at too high a temperature are marked, so that an accurate and sensitive method of temperature determination becomes necessary for consistently satisfactory results. In all modern foundries aluminium is melted under pyrometric control, and the temperature of the metal immediately before pouring is also checked by immersion pyrometers. The pyrometers employed are usually of the thermo-couple type, in which the temperature is indicated by the voltage set up when the junction of two dissimilar metals is heated, the voltage being indicated by an electrical instrument calibrated to read temperatures direct. The two metals for the thermo-couple are usually iron and constantan (an alloy of copper and nickel), and they may be in the form of two wires welded together at the ends, or the constantan wire can be enclosed within an iron tube with insulating material between, like the core of a lead pencil. The active elements are usually encased in an outer protecting sheath, and though this may satisfactorily be used in the furnace room, it involves too great a time lag in the reading to be employed for determining the temperature of the metal just prior to pouring. For pyrometers used for the latter purpose there is no objection to removing the outer sheath, although this limits the life of the junction : but, as the elements may be used throughout their length it is only necessary when the junction gives out to re-weld from time to time. In the pencil type of thermo-couple the life of the iron tube may be prolonged by giving it a coating of the graphite and whiting wash previously referred to. With the two-wire type of junction it is necessary to see that the molten metal

does not short-circuit the elements, so that the wires should be well separated and only the welded tip dipped into the melt.

Pyrometers should be checked from time to time, because they are usually subjected to very rough handling, and may readily be deranged. The method employed is to immerse the junction into a small quantity of molten metal or fused salt of known melting-point, and to watch the readings of the pyrometer as the temperature falls. The melting-point will be very easily distinguished because during solidification the temperature fall is arrested for an appreciable time, and when this occurs the indication of the pyrometer should be equal to the known melting-point. The materials employed may be pure aluminium (solidification point, 658·7° C.), pure zinc (419·4° C.), and pure sodium chloride (801° C.).

Fluxes.

In the melting of aluminium the use of a flux is often recommended to assist in the removal of oxide, but it is doubtful whether any great advantage is to be obtained from its use except in the melting of a mass of small chips, as will be described later. The fluxes used may be mixtures of halogen salts which, in the molten condition, actively attack aluminium oxide, or they may consist of volatile salts, such as zinc chloride, which cause the breaking up of the oxide by dissociation rather than by true solution. Halogen fluxes, of which a typical example consists of 15 per cent. fluorspar (calcium fluoride) with 85 per cent. common salt (sodium chloride), dissolve the oxide with the formation of a viscous slag on the surface, which serves as a protection against further oxidation. Theoretically, therefore, such fluxes should improve the metal and reduce dross loss, but it must be remembered that when a flux is not used the normal skin of oxide which forms on the surface of the melt will itself prevent excessive oxidation, unless the metal is melted under extremely bad control. Under normal conditions the reduction in dross loss following the use of a flux is not great. Further, while the possible contamina-

tion of the metal by oxide inclusions is prevented, the danger of flux inclusions is introduced, for the molten flux has a specific gravity not very different from that of the molten metal. Flux inclusions in the casting are more serious than oxide inclusions, in that they lead to corrosion. A further objection to the use of fluoride fluxes is that they attack silicious materials, such as fireclay, with great rapidity, so that they reduce the life of furnace linings and crucibles.

Melting Scrap.

In the regular routine of an aluminium foundry a considerable accumulation of scrap material occurs in the form of runners and risers, skimmings and spills, borings and turnings, grindings and sawings, and while the larger masses are readily dealt with, the melting of small particles presents considerable difficulty. Large scrap is added directly to the ordinary melting-pots with new metal, and will not detract from the quality of the melt. Indeed, some founders consider that the remelted scrap is beneficial, and always employ a certain percentage (30 per cent.) of good scrap with every melt. It is unnecessary to point out that where a foundry is dealing with several different alloys care must be taken to keep risers, etc., properly separated according to their composition, otherwise the resultant melt is only suitable for second-grade castings where quality is of little importance.

The skimmings and dross from the melting-pots contain quite considerable quantities of metal, with, of course, much oxide, and in the practice of a well-arranged foundry the skimmings from all the pots would be transferred immediately to one special pot for metal recovery, taking care to prevent the skimmings from being exposed to the oxidising effect of the air for longer than is absolutely necessary. The treatment consists of adding ½ per cent. by weight of zinc chloride, and after this has been stirred in, the pot is temporarily closed, and the oxide given time to rise. At the end of a few minutes the oxide appears on the surface as a fine powder, which is skimmed

off, and the clear metal beneath poured into ingots. It is stated that almost the whole of the metal content is recoverable by this process.

In the melting of borings, turnings or sawings, the difficulties experienced arise from the fact that when these are melted each small particle is coated with a tough film of oxide enclosing a globule of molten metal, and the weight of the globule is not sufficient to burst the skin and coalesce with the adjacent globules. Thus, if a mass of chips are put together in a pot and melted, no molten metal is recoverable however high the temperature be raised, unless some means is provided for breaking up the oxide. Two methods are employed. In the first the oxide is removed by means of a flux, and though zinc chloride, sal-ammoniac, or other volatile fluxes are used, the most satisfactory flux is one which will perform the two functions of dissolving the oxide and producing a liquid slag which not only protects the metal from the air, but also tends to float off particles of dirt and foreign matter which may be introduced with the chips. The conditions to be met are somewhat similar to those involved in oxy-acetylene welding (see Chap. V.), and welding fluxes would be ideal for melting chips were their cost not so excessive as to make the whole process hopelessly uneconomic. In melting, the problem is simplified by the fact that there is no serious objection to raising the temperature of the metal to well above the melting-point, and also by the fact that it is not essential for the flux to act upon the oxide with extreme rapidity. The flux previously mentioned, made up with 15 per cent. of fluorspar with 85 per cent. of common salt, melts at about 750° C. and is sufficiently active at 800° C. to remove the oxide in a few minutes, and excellent metal recoveries are obtainable by mixing the chips with 20 to 30 per cent. of this flux mixture and raising the temperature until the flux becomes reasonably fluid.*

* Measurements of metal recovery obtainable by this and other methods of treatment are recorded by Gillet and James, in Bulletin 108, American Bureau of Mines.

In the second method the oxide films between the molten globules are burst by mechanical puddling. The chips are introduced a little at a time into a pot which, preferably, has a small quantity of new metal at the bottom which has just been brought to a pasty condition. The chips are worked into this pasty mass by continuous puddling with an iron rod. The metal must not be allowed to get liquid or the chips will float and be difficult to work in, and if the temperature rises too much it should be lowered by dropping in a piece of large scrap. When the pot becomes reasonably full the temperature is raised until the metal becomes liquid, about 1 per cent. of sal-ammoniac or zinc chloride is stirred in, the dross skimmed off, and the metal poured.

Of the two methods, the first has the advantage that it is not necessary to expose a man to the heat and fumes of an open furnace for long periods while he puddles, but the flux method has the disadvantage that fairly large quantities of flux are necessary. The flux is not expensive, however, probably not more expensive than the labour cost in the puddling process. As regards efficiency of metal recovery, there is little to choose between two methods where the chips and sawings are clean, but if they are contaminated with dirt or oil the flux method is decidedly preferable because of its cleaning effect.

Mixing Alloys.

In the mixing of aluminium alloys the main difficulty lies in the fact that the different ingredients sometimes melt at widely differing temperatures. For this reason it is evident that in the mixing of a aluminium-copper alloy, for example, it would be inadvisable merely to weigh out the required quantities of the two metals into the furnace crucible, and to raise the temperature until the mass becomes molten, for if the temperature is sufficiently high to melt the copper the aluminium will have been much oxidised due to the over-heating,

while if the melting-point of the aluminium itself is not greatly exceeded excessive oxidation will still occur owing to the long period required for the copper to dissolve.

The usual practice in mixing copper-aluminium alloys is to first mix a rich copper " hardener " containing 50 per cent. of copper and 50 per cent. of aluminium, which is made up by first melting a known quantity of copper in one crucible and adding aluminium to this, in lumps, until the correct proportions are obtained. The melting-point of the 50/50 hardener is low, and the addition of the cold aluminium will enable the temperature of the melt to be kept only just above the melting-point of the alloy.

An alternative method of mixing the rich copper hardener is to melt copper and aluminium in separate crucibles and to pour the copper slowly into the molten aluminium. This latter procedure is not so satisfactory as the first method in the case of a 50/50 hardener, because the temperature of the aluminium is apt to be raised unduly high. The process is, however, quite satisfactory with a hardener containing 70 per cent. of aluminium with 30 per cent. of copper. The 70/30 hardener has a lower melting-point than the 50/50 mixture, but the latter is more usually used.

The rich copper hardener is brittle, and easily broken into convenient lumps. It has a low melting-point, and will dissolve very readily in molten aluminium at normal temperatures. In mixing a copper-aluminium alloy, therefore, all that is necessary is to melt a known quantity of aluminium and to add to it the requisite quantity of the hardener.

Zinc alloys are made by adding zinc in lumps directly to molten aluminium, where, owing to the low melting-point of zinc the solution takes place rapidly. Zinc is liable to oxidation during the mixing, so that a small additional amount, say 2 per cent., should be added to compensate for this. For the same reason also, the zinc should be added last in any alloy in which it is to form a part, so that in mixing a zinc-copper-aluminium alloy the aluminium is melted first, copper

is added in the form of the 50/50 hardener, and zinc is added when the copper has completely dissolved.

Silicon alloys can be made by adding solid silicon to molten aluminium, but it is preferable to purchase these alloys from aluminium manufacturers, who produce them in the electric furnace and thereby obtain a superior product.

Nickel is best dealt with in the form of a 20 per cent. hardener, which is made up by adding shot nickel a little at a time to molten aluminium. Care must be taken not to add too much nickel at a time or an infusible mass may separate out at the bottom of the crucible. A temperature of about 850° C. is necessary to cause solution at a reasonable rate.

Magnesium is very highly oxidisable, and being much lighter than aluminium is liable to float on the surface and burn away. The most effective method of making magnesium alloys is to melt the aluminium and to add the magnesium in large lumps held below the surface of the metal until they dissolve. An inverted crucible, bored with a number of holes and fastened to an iron rod, is an effective means of holding the magnesium below the liquid level.

Manganese is obtainable in the pure form, but this is relatively expensive, and for use in the aluminium foundry it is usual to employ ferro-manganese, which is a commercial product obtainable at a reasonable cost. It contains up to 80 per cent. of manganese, and it is found that the small percentage of iron introduced by using this material has no great effect upon the quality of the casting.

Iron is usually added to molten aluminium direct in the form of cuttings of thin sheet. It dissolves slowly unless the temperature is raised to 950° C. or over, and a more satisfactory method is to use an iron-copper-aluminium hardener containing 10 per cent. of iron, 20 per cent. of copper, and 70 per cent. of aluminium. This is made by putting the copper and iron together in a pot and heating up the mixture until melted. The aluminium is melted in a separate pot, and a small quantity, about equal to the weight of iron, is ladled

out and cautiously poured into the molten mixture. The whole is then stirred and when the iron has completely dissolved the mixture is added to the bulk of the molten aluminium.

Purity of Component Metals.

One of the most frequent causes of difficulty in aluminium casting, and one which is the last to be suspected, is the use of impure metals in the alloys used. Aluminium which has been re-melted over and over again will probably contain oxide, which is difficult to detect by chemical analysis, but which may exert a profound influence upon the strength of the finished casting. It is therefore desirable that in mixing alloys a large proportion of the aluminium used should be in the form of virgin metal, and the balance in the form of good clean scrap the history of which is definitely known.

Similarly, the hardening constituents, zinc, copper, nickel, etc., should be of the highest possible grade. The quantities of these metals used is small in comparison with the quantity of aluminium and the cost of the hardening constituents is sufficiently small per lb. of mixed alloy to make inadvisable any attempts at economy by purchasing low-grade materials. Economy in this direction may result in entirely disproportionate costs in scrapped castings or in the replacement of work found faulty in operation. Spelter in particular is obtainable in widely differing qualities, and contains lead in varying quantity. Lead is particularly deleterious in aluminium alloys, and the spelter employed in making zinc alloys should assay not less than 99·5 per cent. of zinc, with a maximum lead content of such a value that the total present in the final alloy will not exceed about 0·1 per cent. Copper used in alloys should similarly be of high-grade quality, and it is preferable to employ the "electrolytic" variety, even though this may cost a few pounds per ton more. Other grades of copper are apt to contain lead, bismuth and arsenic impurities, all of which have definitely deleterious effects on aluminium alloys.

CHAPTER IV.

CASTING

In the casting of aluminium the general principles to be met are exactly those occurring with iron or brass, so that the foundryman new to the metal will have no difficulty in obtaining perfect results if he applies intelligently the same principles which he adopts in the case of the heavier metals. This does not mean that the same methods could be used equally satisfactorily for either iron or aluminium, for the two metals have widely differing characteristics, and points requiring special attention with one metal may occur in the other to a less intense degree. For example, in the case of iron founding special precautions must be taken against "scabbing," i.e. the washing away or dropping of one part of the mould leaving a hole which becomes filled with the metal; in the case of aluminium the lighter weight greatly lessens this danger and "scabbing" is of rare occurrence. On the other hand, the shrinkage of the metal on cooling is greater in the case of aluminium than in iron, so that greater precautions must be taken for the prevention of draws or cracks. Again, with iron or brass the high specific gravity of the metal gives rise to a tendency for the lifting of cores, which must, therefore, be supported by chaplets or reinforced by nails. With aluminium this tendency is very greatly reduced, and only in very special cases would extra precautions be necessary to prevent failure through this cause

Briefly then, a thorough knowledge of the physical characteristics of aluminium with a common-sense application of

normal foundry principles to meet them, is all that is necessary to ensure success in aluminium casting.

Sand.

In view of the light weight of aluminium and its property of filming with a skin of oxide, it will have less ability than other metals to expel air from the mould and completely fill sharp corners, and thus the moulds must be specially porous. Further, the high contraction of the metal and the tendency for hot-shortness necessitate that the mould and cores shall be yielding, so as to apply as little restraint against contraction as possible. These factors point to the desirability of the use of a very lightly rammed green-sand mould, and, wherever possible, green-sand cores.

Green sand is the name given to sand in its natural condition, and consists of silica grains with a natural addition of clay which acts as a binder. In the case of iron the new sand is tempered before use by mixing with it a proportion of old burnt sand to dilute the amount of clay binder, and a proportion of coal dust which gives rise to a film of gas between the surface of the hot metal and the mould, and so leads to a cleaner surface. With aluminium, coal dust is not necessary, for the pouring temperature being very low there is no tendency for the sand to adhere to the metal. Furthermore, the clay content of the sand is not burnt out, so that the sand may be used over and over again with merely the addition of extra water.

In this tempering the best practice is to sprinkle water from a rose nozzle on to the sand immediately it has been knocked out from a mould, while it is still hot. The tempering is thus done by steam and not by drops of water, and this provides a much more even penetration of the dried clay particles. Too much water is harmful, since large quantities of steam would be formed in the mould on pouring, resulting in blow-holes in the casting, and the moulder quickly gets to know by experience just the right amount of water to add.

The feel of the sand when making the mould is a guide; it should be just sufficiently damp to stick together when squeezed, but not so damp that it will stick to the fingers.

A small proportion of new sand may be added from time to time to counteract the slow loss of binding power which occurs after prolonged re-use, and it is, of course, necessary that after once being used the sand be carefully riddled. There is, however, with aluminium none of the complicated sand tempering process required with iron, and this, with the low sand consumption, constitutes a valuable economic advantage in the foundry.

Cores.

Cores must be fragile so that they crush easily when the metal contracts. Unless the core is large or specially complicated, green sand is usually quite satisfactory if, after manufacture, the cores are sprayed with a solution of treacle and water and skin-dried to give sufficient rigidity for reasonable handling. When the core is too large for this practice, the hard unyielding effect of a dry-sand core can be avoided by making the core in two parts, the top half in green sand and the bottom half in dry sand.

A dry-sand core is made of new moulding sand, but is baked after formation in order to harden the clay. It has, therefore, little ability to yield, and a superior alternative is to make the core of sea sand (which has no clay content) bound with a material which softens under heat. Resin, for example, is often recommended, but this has the disadvantage that unless the core is knocked out from the casting while it is still hot, it solidifies, on cooling, into a hard mass which is exceedingly difficult to remove. Various special core binders are upon the market—the majority of which consist of linseed oil and treacle in various proportions, with or without additional ingredients—and the founder will usually find it economical to employ one or other of such proprietary binders, first making his selection with care.

Moulding Boxes.

Aluminium castings are rarely of large size, and because of their low weight much of the output of an aluminium foundry can be made in snap flasks, i.e. moulding boxes which can be removed from the sand as the mould is made, leaving the rammed sand alone on the bench or floor to await pouring, while the moulding box is used for the next mould. The same process is, of course, used with iron and brass founding, but the much greater fluid pressure of these metals on pouring limits the application of the snap flask to comparatively small parts.

Moulding boxes can be purchased ready-made, but in the majority of aluminium foundries they are specially cast in aluminium, and may thus be made of the best size to suit the class of work being done. Aluminium moulding boxes have the advantage of being extremely light to handle, and they can be cast in any low-grade metal—re-melted skimmings, etc.—which it would be unsafe to use in important castings for customers.

Moulding.

In the actual manufacture of the mould for aluminium the first essential is to obtain the maximum of porosity in the sand, and for this reason the sand must be rammed much less heavily than in the case of iron or brass. The amount of ramming will necessarily depend upon the nature of the job, light sections, for example, requiring the least possible tamping consistent with the ability of the mould to hang together against the wash of the metal, in order that the shrinkage shall have the maximum play. Heavy sections, on the other hand, where shrinkage effects are more readily dealt with, can be permitted somewhat heavier ramming.

Consistency and evenness of ramming is greatly facilitated by machine moulding. Repetition jobs, when moulded on one of the numerous designs of vibrating or jolting machines upon the market, can be turned out with the same degree of sand

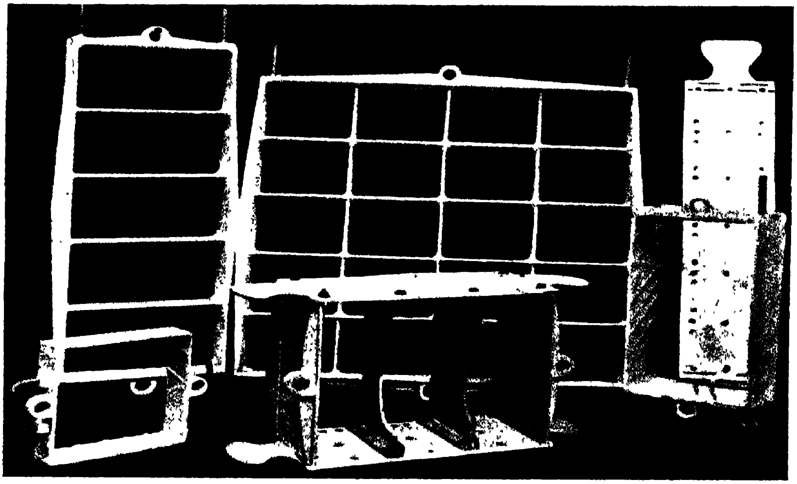


FIG. 19.—Cast aluminium moulding boxes.

[*To face page* 74.

packing every time, so that, once having determined by trial the best amount, all subsequent moulds can be made identical. This is a very important factor, for the success of aluminium founding depends very largely upon the degree of ramming.

Having, by light ramming, obtained a mould from which air and gas can escape easily, it may still be necessary to provide extra vent holes at remote parts of the mould, where the metal, having been cooled by flowing through much cold sand, may arrive at a temperature but little above its pasty stage. It is true that a more perfect filling of sharp corners which become rounded by this cause could be obtained by pouring at a higher temperature, but for reasons which have already been explained it is desirable to keep the pouring temperature as low as possible, or still more serious defects will develop.

In such cases, therefore, a better solution lies in piercing the mould, while the pattern is still in place, with a wire about $\frac{1}{8}$-inch diameter, forcing this through the sand, in the plane where special venting is required, until it touches the pattern.

The cores must also be well ventilated, particularly dry-sand cores which have little porosity, and in these the use of wax threads incorporated in the core during manufacture, and subsequently burnt out on baking, can be recommended.

Finally, before leaving the subject of venting, it must be pointed out that the air actually displaced by the molten metal is not the only volume which must be allowed for. A considerable quantity of air is held between the particles of sand throughout the mould, particularly as the mould is only loosely packed, and when this air becomes heated it expands and must be permitted to escape freely. The heated air will tend to rise, so that that occurring above the casting will naturally escape through the top of the mould, but that beneath the casting will tend to escape *through the molten metal* unless an easier exit is provided elsewhere. In the case of iron and brass, little difficulty is experienced from this effect because of the high density of the metal, but with aluminium it is quite possible for the rising air to cause porosity or to result in a poor surface. The

difficulty is very greatly relieved when snap flasks are used, for the air can then escape through the sides as well as the top. In other cases the difficulty can be obviated by—

(a) Placing the mould on a perforated plate clear of the floor, so that the air has a free passage downwards;
(b) Increasing the height of the runners and risers so as to put the metal under a certain amount of liquid pressure during its solidification.

In this connection it should be pointed out that the pressure applied to the solidifying metal depends only upon the height by which the metal in the pouring gate stands above the casting. It is not in any way increased by increasing the diameter of the gates or risers, so that in order to obtain the maximum of pressure the only method is to use a very deep cope, or alternatively to provide an additional cope whose sole purpose is to increase the height of the runners and risers. Unfortunately, it is not possible to apply very much pressure by these means. In order to equal the pressure ordinarily obtained in brass moulding, for instance, it would be necessary with aluminium to have risers three times as high, and such a condition is obviously out of the question. However, even an inch or two of additional height is of marked effect with aluminium, not only as regards providing back pressure to oppose the passage of air and steam through the molten metal, but also in facilitating the proper filling of sharp corners.

One further means of limiting the effects of expanding gas lies in the method of placing the pattern in the mould. In the case of a large hollow vessel, a saucepan for example, an economical method with iron would be to mould this upside down, so that the pattern leaves its own core in the drag half of the mould. With aluminium it would be desirable to mould the vessel with the open top upwards, even though this may necessitate special supports for the hanging core; for in this position the large volume of air in the core can escape naturally through the open top, whereas if the only outlet for this air

were placed downwards escape through the thin enclosing walls of molten metal would be almost inevitable.

Mould Finishing.

Green-sand moulds may be skin dried by means of a hand torch or gas blow-pipe to ensure that the sand actually in contact with the molten metal shall be free from water, and thus to avoid the marking of the surface by steam. This drying should, of course, be carried out only a short time before pouring, otherwise moisture from the still damp sand beneath the surface will percolate through, and the effect of skin drying will be lost.

When the mould contains chills this drying is specially important, because dampness in the mould will condense upon the chill surfaces in the form of minute drops of water, and these constitute a prolific cause of surface defects. If the chill is hot, condensation will not occur, but it is necessary, if this is relied upon, that the heating of the chills be done immediately before pouring.

For the production of a clean white surface which is characteristic of first-class casting in aluminium, the mould surfaces must be finished off with a fine sleeking. Graphite, flour, and other carbonaceous materials used with iron or brass are not recommended with aluminium, since they tend to give a dull finish, and superior results are obtained with french chalk or lycopodium powder applied lightly by dusting through a linen bag.

Shrinkage.

Some indication of the amount of shrinkage which is to be expected in casting can be obtained by pouring a bar of the metal into a mould between two plates which are held rigidly 1 foot apart. When the metal solidifies and cools the contraction will leave a gap at the ends which can be measured. The method is not altogether satisfactory, since the results obtained will depend upon the temperature of pouring, the size of test

bar, and the type of mould; however, the contraction per foot of length need not be known to any extreme accuracy, for in practice the contraction will not necessarily be the same for two different kinds of casting, even though the same alloy be employed, and indeed, the linear contraction of one part may be different from that of another part of the same casting. The results obtained in experimental measurements are of some value as showing the general nature of the allowance

TABLE XII.

SHRINKAGE OF ALUMINIUM ALLOYS.

Composition	Shrinkage.	
	Ins. per ft.	Per cent.
Pure Aluminium	·198	1·65
4 Cu	·163	1·36
8 Cu	·161	1·34
8 Cu, 2 Fe	·155	1·29
8 Cu, 1 Fe	·149	1·24
8 Cu, 1 Mg	·149	1·24
8 Cu, 1 Mn	·157	1·31
8 Cu, 2 Ni	·154	1·28
10 Cu	·150	1·25
10 Cu, 1·25 Sn	·146	1·22
12 Cu	·147	1·22
14 Cu	·145	1·21
14 Cu, 1 Mn	·145	1·21
10 Zn	·175	1·46
15 Zn	·170	1·42
13½ Zn, 2½ Cu	·150	1·25
20 Zn, 3 Cu	·150	1·25
4 Mg	·166	1·38
11 Si	·150	1·25
13 Si	·140	1·17

which should be made in pattern-making in order that the finished casting shall conform as closely as possible to the required dimensions. The figures for contraction published by different experimenters using different methods are appreciably varied, but average values for common aluminium alloys are given in Table XII., which may be used with sufficient accuracy for all practical purposes. It will be observed that the differences between the shrinkage figures for the different

alloys are not very great, and usually the same allowance of about 5/32-inch per foot would be used for all. When casting in metal moulds a rather lower shrinkage allowance, about ⅛-inch per foot, is sometimes used.

Corresponding figures for the shrinkage per foot of iron and brass are 0·12-inch and 0·15-inch respectively, so that though the shrinkage of aluminium alloys is somewhat high, it is not excessively so in comparison with other metals. Nevertheless, particular care has to be taken in the mould design for aluminium, because the shrinkage is accompanied by hot-shortness, and only by a careful selection of the position of gates, runners, and risers, can shrinkage defects be avoided.

The subject is of such importance that an elementary study of the manner in which shrinkage takes place is well justified.

The total amount of shrinkage is made up of three distinct parts: (*a*) the volume contraction in the liquid metal as it cools to the solidifying point, following the normal law that all substances, whether liquid or solid, contract on cooling; (*b*) the contraction which takes place on changing from the liquid to the solid condition; and (*c*) the solid contraction, similar to the liquid contraction, which occurs in the casting when it cools from the solidifying point to the normal temperature.* Of these the thermal contractions (*a*) and (*c*) depend on the temperature fall and do not vary greatly with the alloy composition, since all aluminium alloys have about the same coefficient of expansion and do not differ widely in melting-point. The liquid contraction gives rise to difficulty when certain parts of the casting solidify first in such a way as to cut off still molten portions from a feeding supply of liquid metal. Such conditions are not always avoidable, and the possible amount of liquid contraction should, therefore, be reduced to a minimum by pouring at the lowest possible temperature.

A reduction in the pouring temperature will not in any way reduce the solid contraction (*c*) since this depends upon the

temperature of solidification and the thermal coefficient, both of which are outside control. The effects of solid contraction are quite different from those of liquid contraction and can be much more serious, for liquid contraction may cause the formation of hollows in the surface or the rounding of corners, whereas solid contraction is manifested in warping, cracking, or internal strains, which seriously reduce the strength of the casting.

The ill-effects are largely due to the inability of the mould to yield, for the contraction *per se*, if unrestricted, does not necessarily subject the casting to stress. It follows, therefore, that much trouble is avoidable, first by light ramming of the mould, and secondly by turning out the casting as soon as possible after solidification.

Knocking out must be done with extreme care, for in its hot condition the casting is extremely fragile, and rough handling in such a condition may cause more damage than the shrinkage effects it is desired to avoid.

Moreover, however rapidly the casting is knocked out, shrinkage strains may occur unless all parts of the casting have solidified at approximately the same time, so that the casting is at the same temperature all over when it is knocked out. Consider, for example, the case of the simple hand wheel casting illustrated in Fig. 20. With this arrangement of pouring, the rim would be expected to solidify before the central boss and spokes, firstly because it is on the outside, secondly because the metal has cooled in passing through the spokes before it reaches the rim, and thirdly because the rim is remote from the central pouring gate, which is to be regarded as a source of heat.

The dotted lines represent, in an exaggerated manner, the size of the rim when the whole of the metal was molten. When the central portions, shown shaded in the plan, are about to solidify, the rim has already solidified and has contracted to the position shown by the full lines. If the mould is sufficiently yielding this contraction will have imposed no stresses on the casting, for the central portions are still liquid. When the

central portions solidify the mould is knocked out and the contraction proceeds, but the rim has already contracted by the amount 2CD, so that it has not much further to go, whereas the spoke AB has only just begun on its solid contraction, and will shrink not only by the amount which the rim has still to go, but also by an amount equal to 2CD. It is possible, therefore, that the spokes will be found broken, probably at a point close to the boss, and there will be a gap between the broken ends approximately equal to the distance CD.

More even cooling, and hence less likelihood of failure, is obtained by gating at the rim, and though a riser would be necessary at the central boss, it would be bad practice to attempt economy by making this a pouring gate. It may here be remarked that it is generally desirable to be liberal as regards the number of gates, runners and risers when casting aluminium, for economy of metal in this respect will often lead to extravagance in scrapped castings. Nevertheless, it is not to be taken as a rigid rule that aluminium castings must not be gated at heavy masses, since for certain cases this would be excellent practice, and in designing a mould the worker must rely upon his common sense rather than upon rigid precepts.

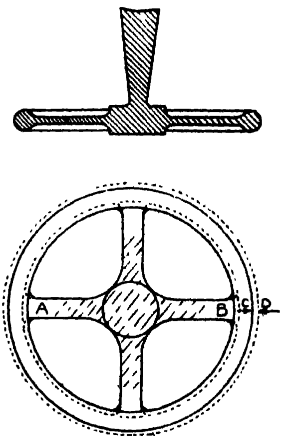


FIG. 20.—Hand wheel gated at the boss, showing exaggerated contraction effects

Crystallisation Shrinkage.

The shrinkage which takes place when the metal changes from the liquid to the solid state is in quite a different category from the thermal shrinkages we have been discussing. It is independent of the temperature fall, but depends largely upon the alloy composition, for in this respect the different elements

behave very differently. The low shrinkage of the aluminium-silicon alloys, for example, has been ascribed to the fact that while aluminium itself contracts on solidifying, as do most metals, silicon is an exception and expands.

The crystallisation shrinkage takes place over the small range of temperature between the point where solidification begins and that at which it is complete. This varies with the alloy composition, and, as has been pointed out, while certain alloys solidify practically instantaneously, others pass through a pasty stage before coming completely solid. The behaviour of the metal in this respect will have a bearing on the effects of the crystallisation shrinkage, for if the alloy contains ingredients of high melting-point these will crystallise out in a honeycomb structure within which the main portion of the crystallisation shrinkage will occur. Thus, in an alloy containing large proportions of such metals as iron and manganese, which combine with aluminium to provide strong compounds of high melting-point, crystallisation shrinkage is apt to appear in the form of porosity.

The amount of crystallisation shrinkage is not simple to determine. It is not taken into account in the process by which the figures in Table XII. are obtained, or at most is only partly taken into account, and no allowance is made for it in the pattern scale, since it cannot be counteracted by increasing the pattern size. Some interesting measurements on the subject have been made by J. D. Edwards,* who determined the shrinkage by specific gravity measurements at different temperatures. Based on these measurements the shrinkage can be calculated, and values obtained are given in Table XIII. for pure aluminium and for two different aluminium-silicon alloys.

For other common casting alloys the amount of crystallisation shrinkage lies intermediate between the extreme values for pure aluminium and for the 11·6 per cent. silicon alloy, and

* "Thermal Properties of Aluminium-Silicon Alloys," *Chem. and Met. Eng.*, 24th January, 1923.

it will be apparent that this shrinkage is sufficiently substantial to cause considerable difficulty unless means are taken to counteract it. It is impossible to prevent the shrinkage from occurring, but in a properly designed mould it is arranged that the shrinkage shall occur at some point where it will do no harm, e.g. in the risers. The methods adopted form part of the mental equipment of every well-trained moulder, and differ in no wise from those employed with other metals. With aluminium, special attention must be given to the subject, for while a poorly-designed mould may give satisfactory results

TABLE XIII.

COMPARATIVE VALUES OF THE THREE TYPES OF SHRINKAGE.

	Pure Aluminium (0·2 per cent. Si).			7·8 per cent. Silicon Alloy.			11·6 per cent. Silicon Alloy.		
	Range of Temp., °C.	Volume Shrinkage, per cent.	Linear Shrinkage, ins. per ft.	Range of Temp., °C.	Volume Shrinkage, per cent.	Linear Shrinkage, ins. per ft.	Range of Temp., °C.	Volume Shrinkage, per cent.	Linear Shrinkage, ins. per ft.
Liquid Shrinkage.	800-658	1·7	---	800-610	2·3	—	800-577	2·9	—
Crystallisation Shrinkage.	658	7·1	---	610-577	5·8	--	577	4·1	---
Solid Shrinkage.	658-20	5·0	·241	577-20	4·2	·170	577-20	4·0	·162

with iron or brass, there is a much smaller chance of success with aluminium if the moulder is careless of the elementary principles of good design.

The effects of crystallisation shrinkage take the form of holes either at the surface, or, more commonly, within the mass of the metal where they are not apparent until the casting is machined or until it breaks under stress in service. Such "blow-holes" are more likely to occur in the heaviest parts of the casting which solidify last, but by a skilful disposition of his gates, risers and chills the moulder can arrange that

each part, as it solidifies, is connected with a still liquid supply of metal upon which it can draw. Thus the whole shrinkage is progressively passed on from one part to another until it finally appears in the risers or at other parts where shrinkage is of no moment.

Chills.

A characteristic of aluminium casting is a much more extensive use of chills in the mould than is usual with other metals. In iron casting, chills cause the formation of extremely hard spots which are practically unmachinable, but with aluminium no disadvantage of this sort arises, and, indeed, the chilled portions may be of better quality than the rest of the metal. Chills are, in fact, sometimes incorporated for the express purpose of providing a hard surface with a fine crystalline structure, at special points such as those which are afterwards to be cut with a screw thread.

The normal purpose of a chill is to facilitate the freezing of certain parts so as to obtain a more uniform cooling throughout the casting, and judiciously placed chills will often cure the most persistent case of cracking. Unfortunately, their use is not altogether free from objection, and we have already remarked upon their tendency to "sweat" with consequent surface defects in the casting. Moreover, unless intelligently placed, chills may cure a defect at one part at the expense of internal strains, invisible but none the less dangerous, at others. In Fig. 20, for example, the cracking of the spokes might be prevented by chilling them, but this would not provide a sound casting, for the inevitable shrinkage would then result in draws or internal weakness at the boss. More success is likely by chilling the boss, and it is a fairly general rule that when chills are used they should be placed at the heavier portions of the casting. A still better solution in this particular example is to omit the chills altogether and to obtain the requisite uniformity of cooling by a more careful placing of gates.

Chills for aluminium are usually of cast iron. Aluminium

chills are sometimes used, and are good for rapid chilling owing to their great heat conductivity, but their surface is apt to deteriorate quickly. Brass is also employed for chills, and though such chills may cause a slight discoloration of the surface, this is not serious, especially if, with the rest of the mould, the chill is dusted with lycopodium or french chalk.

Risers.

The function of a riser is to feed a heavy section so as to make up for crystallisation shrinkage. They are specially important where a heavy section is surrounded by thin sections which normally solidify first, since in this case the thin sections in solidifying will draw from the heavy section, and when the latter solidifies the riser must supply metal not only for the shrinkage of the heavy section, but also for that of the lighter sections as well. This, of course, is common with all metals, but because of the high crystallisation shrinkage of aluminium a much more liberal use of risers is usual.

With aluminium the feeding must be automatic. It is common practice in iron casting to assist the feeding action of the riser by puddling with an iron rod, if necessary keeping the riser full of hot metal by pouring in more as the level sinks. This, if applied to aluminium, is thoroughly bad practice, because the riser will carry up with it a proportion of dross and scum which must be left undisturbed, since, as has been pointed out, the difference in specific gravity between the oxide and the metal is not such as to give the oxide a strong tendency to rise. The pouring of live metal into the riser, for whatever purpose, must be rigorously discouraged, since the oxide is likely to be carried down with the live metal into the casting, from which it will not easily rise again.

The metal in the riser must remain liquid until after the solidification of that part of the casting to which it is attached. If the riser solidifies first it will be worse than useless, for not only will it fail in its function of feeding, but it will actually draw metal from the casting and will thus accentuate shrinkage

troubles. It follows, therefore, that the riser should be of considerable bulk, more especially as the metal in it will have passed over more cool sand than the casting itself and hence will naturally be colder. It is quite normal in aluminium castings of fair size, such, for example, as an automobile crankcase, for the total weight of metal in gates and risers to be one-half of the total weight of the casting itself.

The shape of the riser is of importance as well as its bulk. Usually, following the practice with iron, the riser is cone-shaped, with a comparatively small neck where it joins the casting. The object, in iron, is to facilitate the cutting off in the finishing shop, but with aluminium this is of much less moment, because of the readiness with which a band saw will cut through the metal, and it is desirable that the section of the riser where it joins the casting shall be large. It will be appreciated that with a narrow neck there is a possibility that this will solidify before the casting, thus cutting off the bulk of the riser from any feeding action.

In previous paragraphs a careful distinction has been drawn between crystallisation shrinkage and solid contraction, and while the riser is designed to counteract the crystallisation shrinkage it has no remedial effect upon the evils of solid contraction. It has been shown that these latter difficulties are obviated by uniform solidification, and it will be appreciated that in this respect a riser attached to a heavy section will be deleterious in that it tends to delay the solidification of the part which it feeds. The riser may, therefore, give rise to cracking at junctions between a thin section and a heavy boss. The remedy in such a case is to use a large chill at the boss as well as the riser, so that while the riser takes care of the crystallisation shrinkage, the chill reduces the totally different effect of solid contraction.

Gating.

The pouring gates should be so located and be of such a form that, firstly, the casting cools uniformly, and secondly,

that the metal flows into place rapidly but with the least turbulence.

Uniformity of solidification points to the necessity of using several gates disposed symmetrically as far as possible, and since the gates are the hottest zones in the mould it would be logical to apply them to thin sections so that the metal reaches thick sections further away partly cooled through its passage through the sand. It is true that it may then be necessary to provide risers at the thick sections to counteract shrinkage, but this is not invariably the case, and it is possible that the thin sections may be kept molten until after the thick sections have set. A case in point is the dumb-bell-like casting shown in Fig. 21. An obvious way of moulding this would be

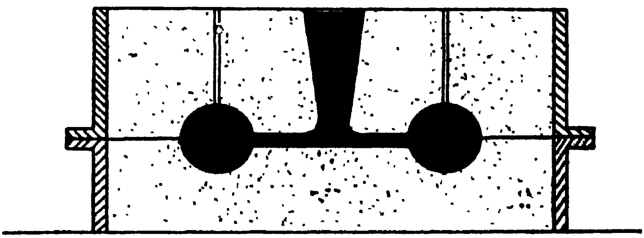


FIG. 21.—Casting gated at a thin section to provide uniformity of cooling.

to place a gate on one ball and a riser on the other, and solidification would then occur in this order, first, the connecting bar, second, the ball attached to the riser, and third, the ball attached to the gate. The shape of the casting is such that this unequal solidification is not likely to cause cracking if the casting is quickly knocked out, but nevertheless a preferable method of gating is shown in the figure, where no risers are employed on the balls, but pouring and feeding is done through a central gate attached to the thin connecting bar. The gate and pouring head are of such a size that the thin section is still liquid when the balls set, but solidifies immediately afterwards. Feeding is progressive, the farthest parts of the casting solidifying first and drawing upon the adjacent liquid parts until the whole of the shrinkage is taken up through the gate.

If the balls had been of unequal size, the gate would be placed somewhat closer to the smaller ball than to the larger, so that the larger ball, which has least cooling ability, receives cooler metal, and the smaller ball is closer to the hot zone round the gate.

It will be seen that in this system the gate operates as the exact opposite of a chill, providing approximate uniformity of solidification by keeping a thin section hot, whereas a chill obtains the same result by the cooling of a thick section. Recognition of this function of a gate will often enable the moulder to obtain the desired freedom from shrinkage defects with a minimum expenditure of waste metal.

The second desideratum in aluminium moulding, rapid pouring, is necessary because the metal should be poured at the lowest possible temperature, and the gates should, therefore, be large in section. Preferably the required total section should be obtained by using several small gates distributed about the casting, and not by a single gate of large capacity. This assists uniformity of solidification, and at the same time permits the section of each gate to conform more closely with the section of the casting to which it is attached. The gate must, of course, solidify after the casting, but it must not be so large that the metal around it is kept molten for a considerable time after the rest of the casting has set. With a single large gate it is often found that the casting close to the junction is spongy and porous, and the reason is that the metal at this point has solidified slowly. In an earlier chapter we have remarked upon the beneficial effect of rapid cooling, and where the casting is to withstand hydraulic pressure it is important that each individual gate shall be small, so that the metal at the junction, though solidifying last, solidifies quickly. With a small gate adequate feeding is often obtained by using a large fillet at the junction.

Pouring without turbulence, in such a way that air can escape freely, is obviously desirable, and the common foundry practice of gating from the bottom, so that the air is carried

up easily with the rising metal is often desirable with aluminium. This practice is, however, by no means suitable for every application, and in the case of a tall casting poured from the bottom the metal will reach the top after passing over a considerable quantity of cool sand. Moreover, at the top the cooling ability of the mould is greatest, so that the casting will solidify very unevenly, and cracking or porosity due to shrinkage strains may result.

When all other means fail to produce castings which are free from defects of obscure origin, the moulder may be able to solve the problem by a process of pouring to which attention has lately been drawn.* In this, the aim is to pour at a steady slow rate through a very small gate placed at one of the highest points of the mould, in such a way that the casting solidifies from the bottom upwards during the pouring. The rate of pouring is nicely adjusted so that the lower parts of the casting are solid while the upper portions of the mould are still unfilled, and feeding to the solid portions is automatic from the shallow layer of liquid metal above. The pouring temperature must necessarily be high, but the objection to this is removed by the fact that the dissolved gases are given time to come out of solution, and the process is said to give a fine and dense quality of metal. No chills or risers are required even though the casting may be a complicated one with wide variations in section, but obviously the attainment of success needs a careful determination by experiment of the proper relation between the pouring temperature and the gate size.

Salvage.

When the mould has been knocked out, the casting should be carefully inspected in its hot condition for slight faults which can be repaired by fusion welding. A surface blow-hole, or a slight mis-run, which might cause the rejection of the casting, can be effectively repaired by building up round the defect a rough mould in sand with a channel for over-flow metal. Into

* George Mortimer, *Inst. Brit. Foundrymen*, March, 1926.

this a liberal stream of hot metal is first poured, so as to raise the temperature of the metal around the defect to the melting-point. The oxide skin at this point is then puddled away with an iron rod beneath the surface of the molten metal surrounding it, and in this way perfect coherence is obtained between the casting and the metal poured on. Excess metal is scraped off while it is still in the pasty stage, and after finishing in the dressing shop on an emery wheel, the repair, if properly done, is undetectable and the casting is in every way equal to a casting perfectly poured in the first place.

A common defect of aluminium castings is porosity, and since this is not necessarily accompanied by a low strength, it is not to be considered sufficient cause for the rejection of the casting unless, of course, the porosity is very pronounced. Nevertheless, for many applications, aluminium castings must be completely watertight, and a porous casting, though satisfactory from the strength point of view, would be valueless. Castings for such purposes should, therefore, be subjected to a porosity test, which need not be elaborate. It is often quite sufficient to plug any openings in the casting, and to fill up with petrol or methylated spirit coloured with some such deep dye as methylene blue. In the case of a flat plate, it may even be sufficient to paint one surface with the coloured spirit. Petrol has an astounding penetrating ability, and if porosity is present small patches of blue colour will appear on the outside of the casting, after ten minutes or so, where the liquid has percolated through.

A more rigid test is to submit the casting to air or water pressure, by completely sealing up all openings and connecting the casting to a hand-pump or a cylinder of compressed air. The pressure employed varies with the conditions under which the casting is to operate in practice, and may lie between 30 to 100 lb./sq. in. When air pressure is used the casting is immersed in water and porosity is indicated by air bubbles; and when water pressure is employed porosity is shown by the formation of beads of " sweat " on the outside.

Castings which show slight porosity can be made fit for use by "doping." A form of this treatment which was largely used during the war for the treatment of aircraft castings, consists of filling the casting, after plugging all openings, with a hot solution of one part of sodium silicate (water-glass) in three to five parts of water. The casting is then connected to a water-pump or to a compressed air cylinder, and a pressure as high as the casting will stand is applied, and maintained until sweating ceases. A period of ten to twenty minutes should be sufficient for the majority of castings, and if a longer time than this is required it may be taken that the porosity is too great to be passed, in that it would most probably be accompanied by poor mechanical properties.

After the sweating ceases the pressure is relieved, the casting thoroughly washed out with hot water, and any white deposits on the surface brushed off.

The action of the water-glass is a chemical one, and results in the formation, within the pores of the casting, of an impermeable deposit of aluminium oxide, which completely fills the pores and seals them.

An alternative process is to employ linseed oil, which is applied under pressure in the same way as the water-glass. When the pores of the casting are completely saturated with the oil, the pressure is released and the oil drained out, and the casting is then stoved for an hour or two. The pores become filled with the oxidation products of the oil and, in some quarters, this is considered preferable to the water-glass process, in that it does not involve any chemical action with the metal itself. When using linseed oil it is not necessary, of course, to use the oil in the pump, and the usual practice is to employ air pressure.

Doping may be applied either before or after machining, although if the sections are thin, or if much metal is to be removed, it is usually best to carry out the process on the final thickness

Gravity Chill Castings.

Aluminium lends itself readily to casting in metal moulds, and a number of processes are employed which vary in respect of the amount of pressure, and the method of applying pressure to the metal during solidification. In Europe the bulk of metal mould castings is produced without any pressure at all other than that of the head of metal in the risers, and castings so produced are variously referred to as die castings, chill castings, gravity castings, etc. It may be remarked that the use of the term " die casting " for describing this process is objectionable in that in America the term is applied exclusively to the process of casting under an externally applied pressure. Castings made in this way differ materially in properties from those produced under the pressure of gravity alone, and confusion arises when the same name is applied to both systems of production.

When no external pressure is applied the casting process only differs from sand casting in that the moulds are of iron instead of sand, but the quality of the product is greatly superior. The physical properties of the metal itself are greatly improved by the rapid solidification ; the surface of the casting is smooth and hard ; a much finer tolerance is permissible in dimensions ; sections can be thinner ; every casting is identical and interchangeable ; and the speed of production is incomparably higher.

The process is not so precise as pressure casting, and while far greater accuracy is obtainable than with sand castings, the process will not completely obviate the necessity for machining. An accuracy in dimensions of not more than 0·01 inch is to be expected ; side walls will have a draft of about 0·01 inch per inch of height, and a corresponding taper will be necessary in all holes.

The designer of a part intended for casting in a gravity chill mould can facilitate production if he bears in mind the limitations of the process. It would be uneconomical, for example, to require wall thicknesses to be cast less than $\frac{1}{8}$-inch

thick unless the article were very small, and, if a 3/32-inch wall thickness is essential, it would probably be cheaper to cast to ⅛-inch and to machine off the extra 1/32-inch rather than to risk an inordinate percentage of mis-run castings. Similarly, holes less than ⅛-inch in diameter should be drilled rather than cast in, though a centre mark can be provided on the casting for facilitating this drilling. Screw threads can be cast in, but this involves either a collapsible core, which is expensive and is apt to leave a slight flash in the threads, or a core must be used which is screwed out after the casting is made. This screwing out takes time, and one of the advantages of the method, rapid production, is thereby sacrificed. A screw-thread cast in aluminium is by no means as accurate as a machine-cut thread, and it is usually necessary to finish a cast thread with a chaser or to run a tap through. On the whole, therefore, little is to be gained by specifying that internal screw threads are to be cast in, though there is much less objection to the casting of external screw threads if the diameter is not excessively small.

Another point on which the designer of the casting can assist production is to avoid any under-cutting unless this is absolutely essential, since under-cut interstices necessitate a collapsible core containing a central tapered part which is withdrawn first before other sections of the core can be moved.

The problems met with in metal mould casting are, in general, the same as those in sand casting, and the same broad principles will apply in the mould design. Success turns equally upon proper venting, uniform solidification, adequate feeding and rapid knocking out. Because of the complete absence of yield in a metal mould, however, the danger of shrinkage defects is greater, and the precautions taken against these are threefold :—

(a) The alloys used are those with the least hot-shortness. Zinc alloys, for example, are not very satisfactory, nor are the copper alloys containing low percentages of copper, but good results are obtained with alloys containing 8 per cent. to 12 per cent. of copper,

and the silicon alloys and silicon-copper alloys are excellent.

(*b*) The moulds are run at a high temperature so that mould and casting contract together during the cooling. The temperature employed usually lies between 400° C. and 500° C., but even higher temperatures may be employed where no other means will prevent cracking. Good results can, in fact, be obtained with the moulds almost red hot, but this, of course, seriously reduces the life of the mould and would not be recommended as a general practice.

(*c*) The moulds are so arranged that they can very quickly be opened, and the castings ejected as soon as possible after solidification. Rapid ejection is facilitated by giving cores and other loose parts a slight taper and by using a dressing on the cores which acts as a form of lubricant. Mortimer * recommends a mixture of 9 lb. plumbago, with 3 lb. of rouge in 5 gallons of water. This solution is kept well stirred, and the cores, which tend to get over-heated, are occasionally cooled off by dipping them in this mixture. Dressings for the mould itself are not so important, although occasionally a mixture of water-glass and whiting, applied evenly by means of a sprayer, is used.

The moulds may be made of any good quality of cast iron. Tungsten steel is sometimes recommended, but this is far more expensive and, though it provides a longer life, cast iron will usually be found satisfactory for the quantity of castings normally required in this system. Tungsten steel is, however, very desirable for cores, since these are submitted to more serious conditions. They are, for example, completely surrounded by hot metal, and are therefore apt to run much hotter than the rest of the mould.

Mould Design.

In the design of a mould the first point to be decided is the parting line, and here the choice is made by considerations which do not arise in the case of a sand casting. In sand casting the parting line is nearly always arranged at some symmetrical plane of the object, but in an iron mould the parting line is normally arranged at one edge, as indicated in the simple design in Fig. 22. This choice is governed by two factors: venting, and the avoidance of flash marks in conspicuous places. The parting line forms a natural vent through which air escape can be facilitated by milling shallow slots or grooves a few thousandths of an inch deep across the butting faces, and if these are arranged to occur at a sharp edge of the casting the rounding of corners due to the trapping of air is avoided. The parting line is usually marked on the casting by a slight ridge or flash, and while this is not unsightly it is best to make it as inconspicuous as possible by arranging that it occurs at the edge of the casting.

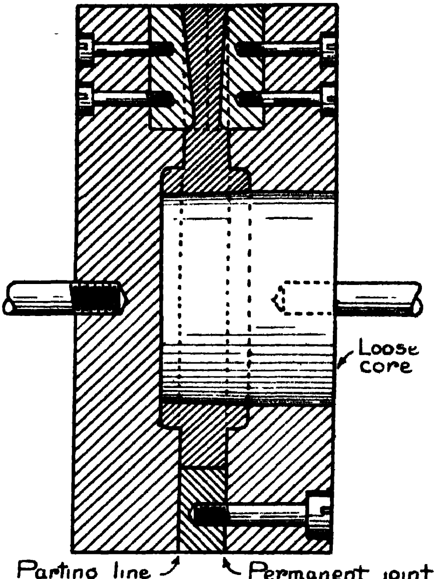


FIG. 22.—Elements of construction of a metal mould.

The same factors apply at other joints of the mould which are not intended to be opened. In the interests of economy the mould is normally built up of several pieces screwed permanently together as shown in Fig. 22 rather than by milling out the shape from a solid block of metal. These permanently

pins are apt to mark the casting when the metal is soft, and when they are employed they should be used in large numbers and should be of large area so as to distribute the pressure well over the surface. They should, of course, be arranged as far as possible to bear upon some portion of the casting where a slight marking is of little importance.

Where the casting is of such a form that feeding presents no difficulties, and adequate venting is obtainable without risers, the gates will be placed at some central position, usually at the top of the casting. Where, as is more usual, a riser is necessary for the free exit of air, if for no other purpose, the gate will usually be placed at one side of the casting, with the riser at the corresponding point on the other side. In this way the riser tends to keep liquid that side of the casting which, being farthest from the gate, would tend to solidify first. The mould shown in Fig. 23 is gated on this principle, and, as will be seen, the riser and gate are of exactly the same form, so that either opening might be used for pouring. In pouring a run of castings from such a mould the two openings would be used alternately as pouring gates for each successive casting, so that the temperature and wear of the mould is more uniform.

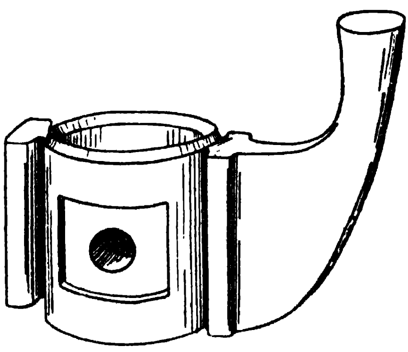


FIG. 24.—Piston casting fed from a distributed gate and shrink pad.

The gate should lead the metal into the mould smoothly, otherwise there is a danger that splashes of metal may solidify by contact with the mould, and become incorporated in the casting to the detriment of strength and appearance. Difficulties due to this or to the entanglement of air, can often be rectified by commencing to pour with the mould tilted, and gradually bringing the mould upright as it fills. The similarity

to the correct process of pouring out a glass of beer from a bottle needs no emphasis.

Pouring from the bottom is rarely employed, even for a comparatively deep casting, although in such a case the casting may be poured through a gate which extends down the whole side. Fig. 24, for example, shows a piston casting, as turned out from a mould designed on this principle. In this particular instance no riser was considered necessary, but shrinkage was taken care of by a shrink pad, also extending the whole depth of the casting, situated on the opposite side from the pouring gate. With this system feeding is automatic and progressive, the casting solidifying from the bottom upwards, and each part drawing upon live liquid metal above it.

Pressure Castings.

It is evident that if the liquid metal be introduced into a metal mould under considerable pressure the attainment of sharp definition will be facilitated, the speed of casting will be increased, and even thinner sections become practicable. The crystallisation shrinkage is partly taken up by the pressure applied, so that gates and risers are small, resulting in economy of metal and, in short, the method is well adapted for the economic production, in large quantities, of a host of small intricate parts, so perfect as regards dimensions and finish that no subsequent machining is necessary.

Various methods are employed for applying pressure, and among them mention must be made of the centrifugal process, in which the mould is poured while it is being rotated at a considerable speed. This method is good and produces excellent castings, but it lacks one of the most important attributes of pressure casting in that the speed of output is even smaller than in the simple gravity chill casting process. In another system, the Cothias process, pressure is applied by pouring into the lower half of the die the right quantity of molten metal, and then forcing the upper part downwards into place by means of a press. The process is somewhat analogous to drop forging,

and is very effective for certain kinds of casting. It is, however, greatly limited in scope, and the bulk of pressure castings is produced in machines consisting essentially of a closed reservoir of molten metal connected by a runner to the mould fixed above. When everything is ready the operator pulls a handle, causing the molten metal to be squirted up the runner by means of compressed gas or a piston and plunger mechanism. Almost immediately afterwards the sprues are cut by a stop cutting through the runner, the cores are drawn, the dies are opened, and the casting is ejected. As far as possible, all these movements are performed automatically, so that once the dies are properly set the whole process is carried out with entirely unskilled labour.

The cost of the machines and dies is very high, so that in spite of the economy of metal, time, and labour, the system is uneconomical unless a very large number of castings is required. The pressure casting system is essentially a mass production process, and though the cost of a simple gravity poured chill mould would often be justified for a hundred castings only, pressure casting would only be economic where the number required runs into thousands.

The process is best applicable where the conditions of working do not call for the maximum available strength in the metal, for the casting operation is not calculated to provide the best possible metallurgical structure. When the metal is first shot into the mould, those portions immediately in contact with the walls solidify practically instantaneously, forming a thin shell within which crystallisation shrinkage takes place; and the result is, that though the outside of the casting may be perfect, the interior is often spongy or contains shrinkage holes. These conditions do not obtain in the case of a gravity chill casting because the solidification takes place progressively, and the crystallisation shrinkage can be counteracted by the methods explained.

While the strength of a pressure die casting is not, therefore, so dependable as that of a gravity chill casting, this does not

count for a great deal in actual practice. The pressure casting process is employed for the production of myriads of small machine parts, casings and covers, bases, and so on, for which purposes adequate strength is readily obtainable, and the field for this class of work is very large. At the present time, millions of small machined brass parts are employed in all conceivable mechanisms where unmachined aluminium die castings would be equally effective, and of less than half the cost, and the growing recognition of this fact is the reason for the very important developments which are occurring in the aluminium die casting business.

CHAPTER V.

OXY-ACETYLENE WELDING.

Applications of the Process.

Among the methods which are employed for the jointing of aluminium none is more generally satisfactory than autogenous welding with the oxy-acetylene blow-pipe. In the hands of an expert the process is simple and rapid, and it can be applied to metal of all thicknesses. The resultant joint is not unsightly, and, indeed, if necessary the weld can be finished off in such a way that it is impossible to detect where the joint exists.

On the other hand, the process is not one which can successfully be practised without experience. Oxy-acetylene welding is a skilled trade, and the technique of welding aluminium differs in many respects from that of welding other metals, so that even a skilled worker in iron and steel cannot make a satisfactory weld in aluminium without practice. Nevertheless, the attainment of consistently good results is within the capabilities of any worker after a little practice, and it may be remarked that in factories dealing with repetition work the oxy-acetylene welding of aluminium is quite commonly done by women.

Oxy-acetylene welding is applied both to the manufacture of articles from aluminium sheet and to the repair of aluminium alloy castings. In these two applications the methods of working are generally the same, though the differences in physical properties may involve slight modifications. Thus, aluminium castings being more brittle than pure aluminium, the danger of cracking due to expansion and contraction effects is more

serious; on the other hand, pure aluminium sheets are normally much thinner than aluminium castings and hence require a more delicate handling of the blow-pipe. For both classes of material certain precautions are necessary for the attainment of reliable welds, and emphasis will be placed in the following paragraphs on the points in which aluminium welding differs from that of iron and steel.

Strength of Welds.

In oxy-acetylene welding the pieces to be joined are laid side by side with the edges butting together. The intense pencil-like flame of the oxy-acetylene blow-pipe is played upon both edges simultaneously, causing them to melt, and, the oxide being removed by a flux or other means, the molten edges flow together and coalesce. Only a very small part of the object is melted at any one time, so that the molten metal is prevented by surface tension from dropping away, and the worker progresses rapidly along the seam, the edges melting under the blow-pipe and solidifying almost immediately as the blow-pipe passes on.

When the joint is completed every portion of the seam has been melted and has solidified again, so that the metal at the seam is in the cast state.

If the two pieces which have been joined are themselves castings, the metal of the seam will have much the same nature as the rest; but if the welded object is made of sheet aluminium the metal at the seam will have materially different properties. Moreover, between the seam itself and the remote parts of the object which have been unaffected by the heat, there will be zones where the metal has been annealed.

In the case of a pure hard-rolled sheet the zones on either side of the weld usually constitute the weakest part, for the thickness at the weld itself can be increased by melting in additional metal during the welding, and the weakness of the cast structure at the seam counteracted by this means. Alternatively, the excess metal at the weld can be hammered down

after the joint is cold, and its strength increased by cold working. The annealed zones on either side remain, however, so that whatever the original temper of the metal the final strength will not be greater than 5 to 6 tons per sq. in.

With alloy castings the conditions are different. The annealing of a cast alloy does not reduce its strength, and, indeed, as has been shown, annealing may improve the physical properties. After a weld has been made in an alloy casting, therefore, the best practice is to hammer over the seam, to ensure a compactness of structure at least equal to that of the rest of the casting, and then to anneal the whole. This annealing also has the effect of removing any internal stresses in the metal which may have been caused by the localised intense heating, and while not sufficient to cause distortion or cracking may be a source of weakness which develops when the casting is submitted to the shocks of practical working.

When subjected to this treatment a weld in a casting should be identical with the rest of the metal, and even if the casting is to be submitted to some form of heat treatment there is no reason why the weld should detract from the results obtained. It may be remarked also that welds in silicon alloy castings would be expected to have much the same strength as the unwelded material, even though this were of the "modified" type, for the rapid melting and solidification during welding should not involve any material reversion of the metal at the weld to the "normal" structure.

Welds in Alloy Sheets.

Simple alloy sheets, such, for example, as the 4 per cent. copper alloy, are readily welded in the same way as pure sheet, and the same sort of conditions apply. Thus, hard-rolled sheets, after welding, will exhibit the three zones: (*a*) cast metal at the weld, which in the case of the 4 per cent. copper alloy would have a tensile strength of some 8 tons/sq. in; (*b*) annealed regions on either side, which would have a strength of about 11 tons/sq. in.; and (*c*) the remote parts of the metal which may have a strength of as much as 20 tons/sq. in.

With heat-treated alloy sheets it would be expected that if the whole object is submitted to heat treatment after welding, the original strength could be regained. While the annealed zones on either side of the line of weld would respond to heat treatment, however, the cast metal at the weld would be much less affected, for, as has been pointed out, aluminium alloys in the cast condition are less susceptible than worked metal. It is true that the weakness at the weld itself could be off-set to some extent by increasing the thickness of the metal at the seam, but this is only a make-shift which would not be permissible in the majority of cases, especially as, in order to be properly effective, the thickness at the weld must be from twice to three times the thickness of the rest.

A much more effective method is to arrange that the cast metal at the weld can be rolled or hammered after completion, so as to bring it into a condition where it is susceptible to heat treatment, and by adopting this method, welds in heat-treated duralumin sheet have been obtained with a tensile strength between 20 and 25 tons/sq. in.

Duralumin is extremely fragile at elevated temperatures, and extreme care must be taken to avoid contraction strains. A light tap is quite sufficient to cause the weld to break when it is still hot, and the danger of cracking is intensified by the fact that the rolled metal is so strong that it is normally used in exceedingly small thicknesses. It has already been pointed out also that the properties of this metal are dependent largely upon the composition, and a very small diminution of the magnesium content due to oxidation during the welding may greatly alter the response of the metal to heat treatment.

It follows, therefore, that while the attainment of excellent results with heat-treated alloy sheet is by no means impossible, it would at present be undesirable to permit this welding for parts of aircraft, for example, or for other applications where all risk of failure must be avoided.

Welding Apparatus.

The apparatus required for the oxy-acetylene welding of aluminium is not different from that required for welding other metals, and consists essentially of a supply of oxygen and of acetylene, with reducing valves and safety valves, and a range of blow-pipes. Oxygen is invariably obtained from cylinders of highly compressed gas (120 atmospheres), but the acetylene may be obtained either from a cylinder of dissolved gas, under a pressure of about 12 atmospheres, or from a low pressure gas generator in which the gas is made on the spot by the interaction of calcium carbide and water.

When using high-pressure acetylene the whole apparatus is portable, the gas is very pure, and the reducing valve which is used on the cylinder ensures that the pressure of the gas remains constant. The flame of the blow-pipe is, therefore, free from variation and the blow-pipe itself is of simple construction, since the two gases are supplied to it at about the same pressure.

The high-pressure system also has the advantage that, in this country at least, it is not subjected to statutory regulation, whereas the storing of carbide for the low-pressure system is only permitted subject to the fulfilment of certain conditions designed to prevent any possibility of danger. With the low-pressure system the gas generator is usually placed outside the welding shop, the gas being brought in through a system of piping, and the generator requires constant attention and cleaning which has no counterpart in the high-pressure system.

On the other hand, the cost per cubic foot of acetylene on the high-pressure system is several times higher than that on the low-pressure system, and the latter is more commonly employed where welding is done upon a large scale. Nevertheless, the advantage of the steady pure flame of the high-pressure blow-pipe is of the greatest assistance in obtaining perfectly even work, and with very thin aluminium sheets it is strongly to be recommended, in spite of its extra cost.

An important auxiliary for the low-pressure generator is a purifier designed to remove from the gas, sulphur and phos-

phorous compounds, lime dust, and other impurities which, if deposited in the weld, would deleteriously affect the strength. It is important that the purifying compound be changed at regular intervals to ensure that the purifier continues to function satisfactorily. The need for re-charging the purifier is indicated by the appearance of the blow-pipe flame itself, since with impure gas this loses its clear, bluish colour and becomes opaque and yellow. A chemical test readily applied is to hold a sheet of white blotting paper soaked in a 10 per cent. solution of silver nitrate in an unlighted jet of the acetylene. The presence of impurities is indicated by the rapid blackening of the paper.

An effective hydraulic safety valve is an essential part of any low-pressure installation, because the pressure of the oxygen at the blow-pipe may be as high as 30 lb. per sq. inch, while the pressure of the acetylene is only about 5 inches water gauge. There is, therefore, a danger that the oxygen may "blow back" along the acetylene pipes and form a highly explosive mixture in the gas generator should the free passage of the mixed gases through the blow-pipe be momentarily impeded. A back-pressure valve is therefore inserted in the acetylene supply piping, and this is a very simple piece of apparatus which acts upon the water seal principle Because of its extreme simplicity, the workers often forget to give it any attention at all, and it should be a fixed rule that before commencing each morning the welder should test the water level, and occasionally clean out the passages to prevent the accumulation of rust.

Blow-Pipes.

Blow-pipes for the high-pressure system are of very simple construction, and for different intensities of flame it is only necessary to change the size of the nozzle. The nozzle is detachable, and a single blow-pipe with a set of nozzles will be suitable for welding the whole range of thickness likely to be met with In the low-pressure blow-pipe the mixing is

effected on the injector principle, i.e. inside the blow-pipe the oxygen emerges at a high velocity from a nozzle which is surrounded by acetylene, and the acetylene is sucked along with the oxygen into an expansion chamber where the velocity is reduced, and intimate mixture takes place, before the gases emerge from the burner nozzle. The injector orifice and the sizes of the various passages in the blow-pipe are designed for one particular oxygen pressure and one particular rate of delivery, so that the " power " of the blow-pipe is not variable, and for welding different sizes of work completely different blow-pipes are usually necessary. Certain manufacturers supply blow-pipes in which the injector, mixing chamber, and burner nozzle can be removed as one unit, so that a range of power is obtainable with one body and a series of interchangeable injector heads.

The blow-pipe must be treated delicately, and should the orifices become stopped up they should be cleaned out with the utmost care. Any enlargement of the orifices is fatal to good work, and even small scratches in the walls of the gas passages are liable to set up minute eddies which may result in back-fires. The burner tip may be cleaned with a piece of very soft aluminium or copper wire and the internal passages may be cleaned by blowing through with oxygen from the nozzle end. The oxygen injector orifice should never be touched, since this is extremely small and easily damaged.

Power of Blow-Pipe.

Blow-pipes are classified according to their consumption of acetylene, which is usually expressed in litres per hour (1 cubic foot equals 28·3 litres). It is not possible economically to vary the pressure of a low-pressure blow-pipe by adjusting the oxygen pressure. The nozzles, injector orifice, mixing chamber and other parts of the blow-pipe are designed for one particular oxygen pressure, and though an increase in this pressure will involve an increase in the consumption of both oxygen and acetylene, the two gases are not then pro-

perly mixed, and the flame is of poor quality. Moreover, there is a wasteful disproportion in the consumption of the two gases. Theoretically, two and a half volumes of oxygen are required to completely burn one volume of acetylene, but in the blow-pipe flame the greater part of the oxygen is provided by the atmosphere, and the consumption of oxygen from the cylinder is only that necessary to form the inner white flame. For this, theoretically, equal volumes of acetylene and oxygen are required, but in practice this relative consumption is only attained in the case of a high-pressure blow-pipe. With low-pressure blow-pipes imperfection in design and bad manipulation invariably involve a greater consumption of oxygen than acetylene, and the ratio of oxygen to acetylene quite usually lies between 1·3 and 1·5. Unless the oxygen pressure is maintained at the value recommended by the maker of the blow-pipe, the disparity in the consumption of the two gases is still further increased.

The selection of the correct size of blow-pipe for any particular work is practically a matter for experience, and although special tables have been prepared giving the rate of acetylene consumption for welding various thicknesses of metal, these tables are only moderately useful, since the size of blow-pipe must depend greatly upon the shape and size of the object to be welded, as well as upon the thickness. The welding of a large tank of aluminium, for example, will require a much more powerful blow-pipe than the welding of a small piece of bar of equal thickness, because the larger object has a larger capacity for heat and a larger radiating surface. Much of the heat poured on the edges of the metal to be welded escapes by conduction to remote parts of the object, where part is absorbed in raising the temperature, and part is radiated away to the air. The blow-pipe must be of sufficient power to melt the edges in spite of this continuous draining away of heat. If the object is small, the radiating surface is small, and the heat which escapes along the thickness of the metal cannot be radiated away quickly enough to prevent the temperature of

the whole object from rising rapidly. The rate of conduction then falls and a small blow-pipe becomes suitable for welding.

This explains also why pre-heating enables a much smaller blow-pipe to be used, and also why, if special cooling arrangements are made to prevent warping, as will be explained later, the size of the blow-pipe must be increased. The appropriate size of blow-pipe will also depend to some extent upon the skill

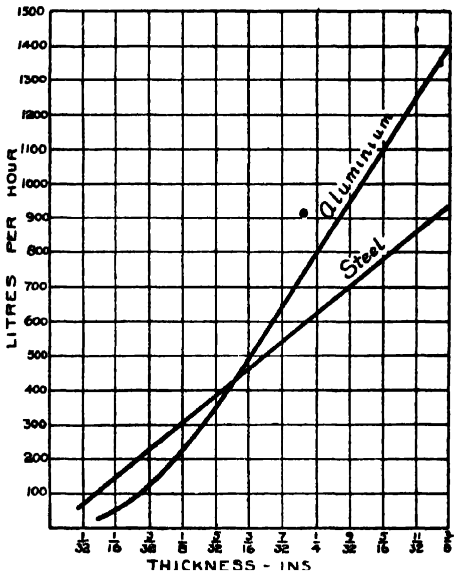


FIG. 25.—Comparative values of acetylene consumption when welding aluminium and steel.

of the worker, for a quick worker will be able to use a large blow-pipe which in the hands of a slower and less-experienced man would result in over-heating and the formation of holes.

As a general rule, for thicknesses of about 3/16-inch the power of blow-pipe required for welding aluminium is about the same as that for an equal thickness of mild steel; since, although the melting-point of aluminium is very much lower, this is counter-balanced by the fact that the heat conductivity is very

much greater. With thin sheets, however, the effect of conductivity is not of so much importance as the effect of the low melting-point, and the blow-pipe for aluminium should be smaller than that for steel. For very large thicknesses the conductivity is of so great an importance that an even larger blow-pipe is necessary for aluminium than for steel. In Fig. 25, approximate values for the acetylene consumption necessary for welding both aluminium and mild steel are shown by way of comparison. These curves are to be taken merely as guides, and considerable variations may be necessary in individual cases.

Flame Adjustment.

The proportion of oxygen and acetylene supplied to the blow-pipe should be so adjusted that there is excess neither of one nor of the other in the flame. The appearance of the flame is an effective indication of the relative proportions. The normal flame consists of two very distinct parts, a white luminous cone at the nozzle, surrounded by a non-luminous bluish portion which itself really consists of two zones. If there is excess of acetylene in the flame the white cone becomes shrouded in a faint whitish mantle more or less large according to the amount of excess acetylene. When the oxygen pressure is correctly set, and both the acetylene and oxygen valves are fully opened, the flame will always have an excess of acetylene unless the blow-pipe is deranged or obstructed. If the acetylene cock is now slowly closed, the whitish mantle begins to grow smaller until at one point it just disappears, and the white cone stands out sharply defined in the blue non-luminous outer zone. This point marks the correct adjustment for welding.

If the acetylene cock is still further closed the white cone begins to grow smaller, and the bluish portion of the flame changes to a violet-blue and becomes less transparent, indicating that there is an excess of oxygen in the flame. Excess of either gas has a bad effect both on the quality of the weld and the

economy of the process. Excess of oxygen leads to oxide inclusions in the weld, and when excess of acetylene is present the surplus gas is forced into the molten bath, producing a bubbling which causes new metal continuously to be presented to the oxidising influences of the atmosphere. Of the two evils excess of oxygen is the more serious when welding aluminium, and so desirable is it that there should be no excess of oxygen that some writers state that the metal should be welded with an excess of acetylene. This practice is not to be recommended.

With the ordinary types of low-pressure blow-pipe the whole of the regulation should be effected by means of the acetylene cock. Once the oxygen pressure has been set to the correct value, no further adjustment in the oxygen supply must be made. If, for example, there is an excess of oxygen in the flame, no attempt should be made to correct this by adjusting the oxygen valves at the blow-pipe or on the cylinder, and the remedy is to open the acetylene valve a little wider.

After the blow-pipe has been in use for some time it will be found that, though correctly adjusted at first, the flame begins to exhibit the characteristics of excess oxygen. This is due to the heating up of the blow-pipe and the expansion of the acetylene to a greater degree than the oxygen, and the welder should remember to remedy this variation.

Flux.

It has been stated that the production of a weld in aluminium necessitates the removal of the oxide formed on the surface. Two pieces of aluminium placed in contact and melted will not coalesce, because each will be isolated by a thick and tough skin of oxide formed during the heating. The two molten edges will flow together, however, if the oxide skin of each is pickled, allowing the clear molten metal to come into contact, in the same way that two soap bubbles brought into contact will coalesce into one if the dividing wall is pierced.

The removal of the oxide skin in aluminium welding may be done either by mechanical puddling, or by the use of some

chemical compound which will dissolve the oxide. In the puddling process the welder holds in his left hand an iron or aluminium wire with which he continuously stirs the molten bath as he proceeds. The process can only be applied when the metal to be joined is fairly thick, and the results are not very satisfactory in that oxide is likely to be left in the weld. Further, the process is slow, and the final appearance of the joint is irregular, necessitating much filing or grinding to obtain a good-looking result.

The use of a flux is much more satisfactory. It has been known for many years that certain chemical salts when in the molten state will dissolve the oxide of aluminium, and by the use of these it is possible to remove the oxide automatically and regularly as the welding proceeds. Various fluxes are upon the market, consisting of mixtures of salts in such proportions that the flux melts before the aluminium, forming a viscous coating beneath which the metal is melted. At the melting-point of aluminium the flux should be sufficiently fluid to cover the joint without being so fluid as to run over the work as a film of insufficient thickness, and the density of the molten flux should be such that there is no danger of inclusion in the weld. Its dissolving action on the oxide should be so quick that the welder can proceed along the seam as rapidly as his skill permits. For this reason, a flux which is good for thick metal may not be the best for thin aluminium, since, when welding thick metal, the speed of progress is necessarily slow, and a slow flux has time to act; with thin metal rapid progress is essential, or the metal will be burnt into holes, and a very rapid flux is necessary. Conversely, a flux suitable for thin sheets may not be suitable for thick ones, since the melting-point of the flux may be so low that under the prolonged heating to which it is subjected when used on thick sheets it may become too fluid and run away from the joint.

It is not suggested, of course, that every different thickness of aluminium requires a different flux, but it is well established that the fluxes chosen by repairers of aluminium castings,

for example, are not necessarily those found most suitable by makers of spun hollow-ware. It is therefore desirable that welders should try several of the different fluxes which are upon the market and choose that which best suits their particular style of working, and the general class of work upon which they are engaged.

The fluxes employed, whether for aluminium alloys or for pure aluminium, are mixtures of alkali halides, and a typical analysis is that given in the Air Board Specification No. L. 13, which manufacturers of aircraft components were required to employ during the war. The composition, which is the same as that recommended by the *Union de la Soudure Autogène*, is as follows :—

Potassium chloride . . .	45 per cent. (by weight).
Sodium chloride . . .	38 ,, ,, ,,
Lithium chloride . . .	15 ,, ,, ,,
Potassium fluoride . . .	7 ,, ,, ,,
Potassium bisulphate . .	3 ,, ,, ,,

While certain large welding firms make up their own fluxes from this or other formulæ, it is usually preferable to purchase the flux ready-made, since the attainment of the necessary intimate mixture of the correct composition is by no means a simple matter owing to the nature of the salts themselves. The melting of all the ingredients together, for example, is not permissible as a means of attaining a proper mixture, because this would cause that interaction between them which it is desired shall occur only during the welding.

Fluxes are all deliquescent, i.e. they become moist when exposed to the air, and they should, therefore, be kept in air-tight receptacles holding not more than, say, a quarter of a pound. When the flux becomes damp it is liable to lose its efficiency owing to the slow inter-action of the components. An improvement in this respect is due to Dr. Briscoe and Capt. Richardson, who have patented the use of a pyrosulphate or pyrophosphate in the mixture instead of a bisulphate. They explain that the activity of a flux is largely due to the liberation of hydrochloric and hydrofluoric acids by the inter-action of

the components under the blow-pipe, and that it is these acids which attack the oxide. The presence of aluminium oxide is not necessary for the action to proceed if the activating agent is a bisulphate, as in the above composition, but if this is replaced by a salt of a polybasic acid, the halogen acids are only liberated in the presence of aluminium oxide. Hence, such a flux is only active during the actual process of welding, and can be stored for much longer periods without deterioration.

Fluxes are all comparatively expensive, and, therefore, should be used with economy. When a welding rod is employed, i.e. when additional metal is added by melting in an aluminium wire with the metal of the sheet edges, the most satisfactory method of applying the flux is to use it in the form of a varnish on the rod. The end of the rod is heated and dipped into the tin of flux, when a small quantity adheres in the form of a tuft. This tuft is then melted along the rod, forming a thin coating for a distance of 6 inches or more. It is not then necessary to apply any additional flux to the metal during the welding, for as the rod is melted into the weld the flux will melt with it, and run ahead of the flame, and so prepare the metal in advance. The flux is thus applied just at the point where it is required, and at a uniform rate.

When a welding rod is not employed the flux may be mixed up with water and applied to the edges with a brush.

Aluminium fluxes have a strong corroding action on the metal, and hence must be washed off quickly and thoroughly as soon as the weld is completed. Small articles which are not likely to be damaged by the sudden cooling may be dipped into water as soon as they are welded, when the excess flux will come away cleanly with the slagged oxide. Larger articles, which must be cooled slowly, should be thoroughly scrubbed with hot water along the line of the weld when they are cold.

Blow-Pipe Manipulation.

In the welding of aluminium one of the main points in which the process differs from that of steel is in the speed of working.

The speed is very much greater than with steel, and also the rate of movement along the seam is not uniform but becomes more and more rapid as the object becomes heated. It is just this characteristic of aluminium, and other good heat-conducting metals, that makes a short apprenticeship necessary before regular and good-looking welds may be obtained in these materials.

If the article is thin, and the weld is a long one, it is sometimes found easier to stop about an inch from the end, and to allow the metal to cool a little, before completing the seam. Unless this is done the metal may become so hot at the end that the molten bath becomes excessively wide and the metal may even drop away. To stop and start again in this way is not good practice when it is avoidable, and as far as possible the weld should be completed in one rapid run.

The welding rod is held loosely in the fingers of the left hand, upon which an asbestos glove should be worn, and it is kept in a direct line with the weld. The blow-pipe flame is directed centrally so that it melts simultaneously both the edges of the sheet to be welded and also the end of the welding rod. It is important when starting that the two edges should commence to melt before any filling material is melted, and the welder quickly learns to judge the correct instant to commence running up the seam. The end of the welding rod is kept in the bath the whole time that the welding is being done, so as to reduce the possibility of oxide inclusion. If the rod were held above the bath, and the molten metal allowed to drop from it, or if the welder periodically dips the end of the rod into the molten bath and removes it again, oxide will be carried in which may not be completely removed by the flux before solidification takes place.

The blow-pipe flame should always be directed vertically upon the work, because otherwise the molten metal may be blown along the line of the weld, and come into contact with parts of the metal which have not yet attained the melting temperature. The molten metal then solidifies and adheres to the cold edges,

with the result that these are glued together rather than welded, and a slight stress will break them apart. This defect of "adhesion," as it is termed, is very common with beginners in aluminium welding, especially with thick metal, and it is extremely difficult to detect unless the weld is submitted to a tensile or bending test.

The white cone of the flame should not be allowed to come into contact with the metal, or the weld will be oxidised at that point. The minimum distance varies, according to the power of the blow-pipe, from ⅛-inch to ⅜-inch.

Welding Rod.

The use of a welding rod or feeding stick is necessary with all but the thinnest sheets, and the welding rod should be of the same composition as the metal to be welded. Pure aluminium should be welded with a pure welding stick, and aluminium castings should be welded with a rod of the same alloy. For thin sheet metal the welding rod may be a strip cut from the same sheet, having a width of two to three times the thickness. More generally a round wire is employed, and usual sizes are as given in Table XIV.

TABLE XIV.

SIZES OF WELDING ROD FOR ALUMINIUM AND ALUMINIUM ALLOYS.

Thickness to be Welded.		Welding Wire.	
S.W.G.	Ins.	S.W.G.	Ins.
Up to 19	Up to ·040	14	·080
19 to 18	·040-·048	13	·092
18 ,, 16	·048-·064	12	·104
16 ,, 14	·064-·080	11	·116
14 ,, 12	·080-·104	10	·128
12 ,, 10	·104-·128	9	·144
10 ,, 8	·128-·160	8	·160
8 ,, 5	·160-·212	7	·176
5 ,, 3	·212-·252	6	·192
3 ,, 1	·252-·300	5	·212

When repairing aluminium castings there is often considerable difficulty in choosing the proper composition of the welding rod, in view of the fact that the composition of the metal is not discernible from its appearance. From the welders' point of view there is little difference in the behaviour of the different alloys under the blow-pipe, and a copper-aluminium alloy casting could be repaired without difficulty with a zinc-aluminium alloy welding rod, or even with a pure aluminium welding rod. Unless the welding rod has the same composition as the rest, however, there is danger of corrosion after the repair has been completed and the object put back into use, particularly if this involves its exposure to moisture.

Fortunately, the number of different aluminium alloys now employed for general casting purposes is limited, and in Great Britain the majority of castings are made in the L5 composition, while the No. 12 alloy (i.e. 8 per cent. copper) is preferred in America. When the exact composition of the alloy is unknown the country of origin is, therefore, a useful guide, while in addition an experienced welder can differentiate between a zinc alloy and a copper alloy by the fact that the former will give off fumes of oxide when melted, whereas a simple copper alloy does not.

It may be remarked that special welding sticks are sometimes sold for the repair of aluminium castings, which are claimed to have particular advantages. These often contain large proportions of zinc (up to 40 per cent.) and in consequence are of low melting-point and flow freely. Although they facilitate the work, the danger of corrosion to which they give rise is a serious one, and it is desirable that the welder should specify to the makers exactly what composition he requires in the rods, and should not use any welding stick of which he does not know the composition.

A stock of L5 and No. 12 alloy rods will cover all normal requirements, for though articles to be repaired may contain a quantity of copper or zinc not exactly in conformity with the composition of these two standards, the difference is not likely

to be so great as to cause serious difficulty. The repair of a casting in the L8 alloy (12 per cent. copper), can successfully be done with No. 12 alloy welding sticks without great danger of subsequent corrosion, and similarly alloys containing zinc only can be repaired with an L5 welding stick, the small quantity of copper in the latter being of little moment.

Silicon alloys, and other alloys not approximating to the L5 or No. 12 compositions, must, of course, be welded with special rods of the right analysis.

Preparation of the Edges.

The edges to be welded should be thoroughly cleaned from all dirt and grease, and particular care is needed with aluminium castings, since these are occasionally porous and may contain absorbed oils, which, if not removed, will cause blowholes in the weld. A good plan is to heat the edges before commencing to weld, when the absorbed grease will be sweated out and can be wiped away, the surface being finally cleaned with petrol or benzine.

Even apparently clean surfaces of aluminium are coated with a film of oxide which should be removed as far as possible, and the best cleaning medium is a wire scratch brush such as is used for cleaning files. Not only the edges to be welded, but also the adjacent surfaces above and below, and the welding rod itself, should all be cleaned with the scratch brush.

Practically all welded work is butted. No advantage is to be gained by lapping the plates to be joined as in Fig. 26, for the weakest part of an object after welding is at points such as AA on either side of the joint, where the metal has been annealed. The lapped joint does not, therefore, provide greater strength than the simple butt joint, while at the same time it is twice as expensive as it involves double the work. There is also a danger that the sheet will be thinned at the points AA during the welding, because these points are liable to be raised to the

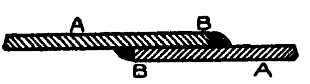


FIG. 26.—Lap weld.

melting-point before the edges BB, from which heat flows away rapidly owing to the double thickness at these points.

For thin sheets of No. 20 s.w.g. and less, the edges to be welded are turned up at right angles, as shown at A in Fig. 27. No welding stick is then used, since the flanges are melted up and provide the requisite filling metal. The flanges should be from one and a half times to twice the thickness of the sheet.

For thicker metals it is preferable simply to butt the edges together as at B, since the flange method is liable to result in oxide inclusions, and should only be employed when other methods are too difficult.

For metal of $\frac{1}{8}$-inch to $\frac{3}{8}$-inch thickness the edges should be

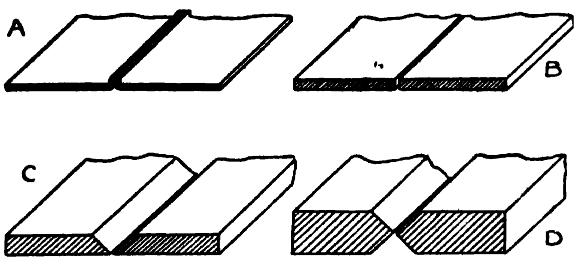


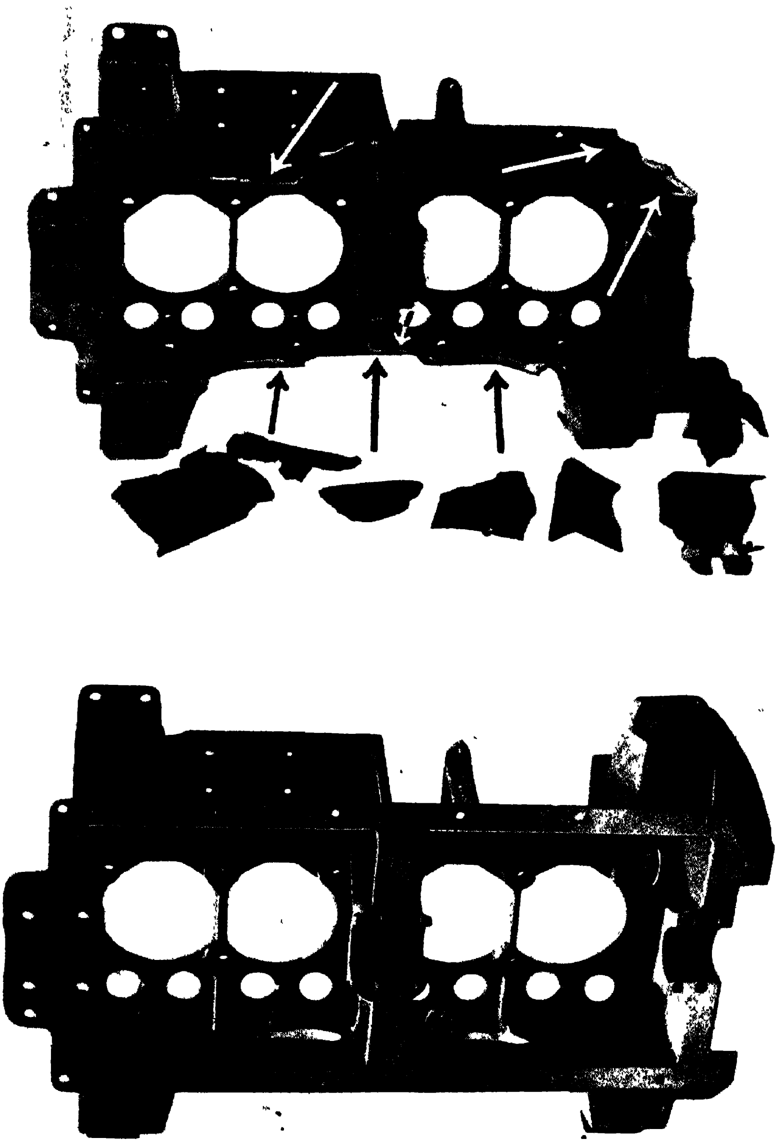
FIG. 27.—Methods of preparing the edges for welding.

bevelled to an angle of 45°, as shown at C, so that when put together a right-angled V is formed, permitting a ready penetration through the whole thickness.

For metal $\frac{1}{2}$-inch and over a double V is desirable, as shown at D, the welding being done in two stages. This limits the width of the molten bath to that required for half the thickness when using a single V, and at the same time it counteracts the tendency to warp.

Supporting the Work.

The work should be so supported that the under-side of the weld is free, in order that the added thickness of metal may form a slight bulge on the under-surface which can afterwards be filed down if desired. If the two pieces to be joined are laid



FIGS 28A and B.—Badly damaged aluminium crankcase before and after welding. (Messrs. Barimar, Ltd.)

[*To face page* 121.

upon a flat bench it is impossible to make the line of weld on the under-side disappear.

There is no danger of metal falling away during the welding, even when the under-side is unsupported, unless the bath is excessively wide or the thickness dealt with very large. With thick castings it is often desirable to provide some form of backing, and a piece of thin sheet-iron or asbestos board may be used. When repairing hollow castings a convenient method is to apply to the under-side of the repair a paste consisting of one-third plaster of Paris and two-thirds short fibre asbestos. A layer about ½-inch thick should be formed, and this should be allowed to dry slowly. It must be quite dry before the welding is started, and it may be remarked that slow drying is essential, or cracking will result, so that it is useless to attempt to dry quickly with the blow-pipe.

Expansion and Contraction Effects.

The phenomena observed, due to unequal contraction during cooling, which we have already discussed in connection with aluminium casting, also occur in the case of welding. In welding the difficulties may, indeed, be increased, since the heating is necessarily intensely localised, so that the repair of an aluminium casting, in which the danger of cracking is greatest owing to the hot-shortness of the metal, is not to be undertaken without a reasonable degree of knowledge and a large degree of common sense. Many an expensive casting has been ruined by attempts at repair by self-confident but uninformed amateurs, although a specialist in the process can rebuild a cylinder block or crankcase equal in appearance and strength to a new casting from a mass of broken parts seemingly only ready for the scrap heap (Fig. 28).

The underlying principles involved in the avoidance of distortion or cracking after welding are simple to grasp, and once the welder understands them he should have no difficulty in determining what methods he must apply in any particular case to ensure satisfactory results.

The elementary causes of distortion or cracking can be shown by considering two strips placed ready for welding, and so supported that no space is allowed for expansion, as in Fig. 29. On applying the blow-pipe the strips expand and will take up the formation shown in an exaggerated form at B. On continued heating the edges melt, and the strain due to the initial expansion is now taken up in the molten bath, as shown at C. The weld is then allowed to cool, the molten metal solidifies and the whole contracts, with the result that the total over-all length is appreciably less than the initial length, as indicated at D.

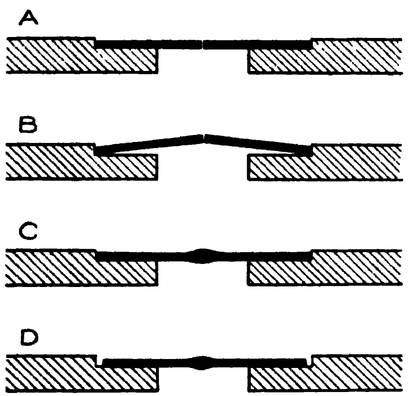


FIG. 29.—Illustrating the fundamental causes of distortion during and after welding.

It would require very large forces to prevent this contraction from taking place, and if the strips were held rigidly it is likely that the weld would be torn open by the contraction forces, unless the strips themselves yield.

We can now consider the application of these phenomena to practical cases. It is well known that if two sheets are placed for welding with the edges close together the far edges will be seen to open out when the welder first applies his blow-pipe, and that as he proceeds the gap closes, until finally the far edges overlap.

A complete explanation is provided by the effects illustrated in Fig. 29. When the blow-pipe is applied at a point such as B in Fig. 30, the metal at that point expands and the edges press tightly against one another, so that the far parts of the sheet at A are opened out, and the small length of metal already welded is put into compression. The edges then melt, and the strain is relieved, so that the far edges come together

again; but when the molten bath solidifies and the blow-pipe passes on, contraction occurs with a complete reversal of the previous action, i.e. the far edges are pulled closer together and the part already welded experiences a tensile stress.

At the next fraction of an inch along the weld, the process is repeated, and the contraction which there takes place is added to that which has previously occurred. It follows that, though the contraction at each point along the weld may be small, the sum effect is large, and before he has gone 6 inches along the seam the welder may find the far edges overlapping by ⅛-inch; alternatively, if the sheets are too thick to overlap, the tensile forces produced in the part already welded may cause this to crack.

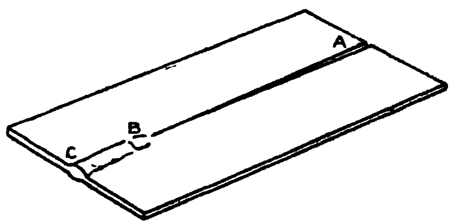


FIG. 30.—Distortion in a simple weld between two plates.

One obvious remedy is to start with the edges slightly inclined to one another, the width of gap increasing by about ¼-inch per foot along the whole length. This is the best method, but it cannot always be adopted, and an alternative is to "tack" the sheets together by a series of little welds about ⅜-inch long, spaced at intervals of about 1½ inches along the whole line of the weld. In this case the tacks will hold the edges together, but the contraction forces may then cause a slight buckling of the sheet in the plane at right angles to the line of weld. This is not serious, as the buckling is not cumulative and the work can usually be flattened by hammering after completion. The tacks should not be applied progressively from one end, or the overlapping of the edges will occur during the tacking, and the first tack should be made at the centre and the others alternately on either side.

A second well-known example of distortion is shown in Fig. 31. Here a disc is being welded into the end of a cylinder,

but if the welder commences at one point and proceeds regularly round the edge he will find that a gap develops and the cylinder becomes distorted as shown at A. This effect is due to exactly the same cause as in Fig. 30. The gap between the disc and cylinder here represents the total amount of contraction which has taken place over the whole length of welding. The remedy is to tack strongly, as shown at B in Fig. 31, in the order indicated, and to carry out the weld in sections, first from 5 to 3, then from 4 to 6, next from 2 to 8, and then from 7 to 1, and so on until the whole is complete. The contraction does not then become cumulative, and is taken up by a slight diminution in the overall diameter of the cylinder, which, being

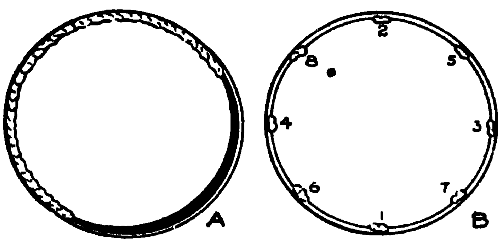


FIG. 31.—Distortion in welding an end to a cylinder, with the remedy.

uniform in all directions, involves no departure from strict circularity.

A still further example is the repair of a broken lug of an exhaust manifold. This, after repair, must have the two parts in perfect alignment, and the distance between the holes must be the same as before the fracture. The latter point is ensured by spacing the two pieces a little apart (1/32-inch) to allow for contraction, and perfect alignment is assured by lightly clamping the two parts on to a surface plate, and tacking. The actual welding should be done on the welding bench and not in the surface plate, or local chilling will cause warping.

In certain cases, distortion, cracking, or the alteration of dimensions, can be prevented by limiting the amount of expansion to that occurring at the weld itself. Suppose, for example, that the whole article to be welded can be immersed

in water so that only the parts to be welded are above the surface; then, as the temperature of the immersed parts cannot rise above the boiling-point of water the contraction effects after welding are small. Complete immersion in this way is rarely practicable, but a similar effect is obtained by wrapping the parts immediately surrounding the line of weld with asbestos wool kept soaked with water. With this method an extremely powerful blow-pipe is necessary, but the process is a useful one for the welder to keep in mind for use where no other system will provide the required results.

Pre-heating.

A further method of preventing distortion is pre-heating, and this is of the greatest importance in that it is a universal remedy which is beneficial in all cases. If the whole object is maintained at a temperature not very greatly below the melting-point, then, when the blow-pipe is applied to any one point, the additional expansion of this will be small and is unlikely to cause distortion. Moreover, when the whole object is finally allowed to cool down the contraction will equal the initial expansion during pre-heating, and the final dimensions will be the same as the initial dimensions.

Pre-heating also has the advantage that it will limit the consumption of oxygen and acetylene to that required for the actual melting of the seam. The welding gases are expensive, and if the bulk of the heat can be provided by a furnace or other pre-heating means the economy of the process is improved.

The pre-heating of the whole object is not always possible, and in such cases contraction effects may be limited by pre-heating certain parts only. A classic example is a ring broken at A as shown in Fig. 32. If this were welded without pre-heating the contraction occurring would result in the distortion of the circular shape and a diminution of the diameter, but if the ring is pre-heated at the section shown shaded, the expansion of this will open out the break and permit expansion to take place freely during welding. Finally, when the weld

is completed, the contraction at the weld and at the pre-heated region will occur together, and the final dimensions of the ring will be unaltered.

Local pre-heating must be applied with care, especially in castings, for the presence of strengthening ribs, or other devices which tend to prevent the free expansion of the parts, can possibly lead to fractures during the pre-heating itself.

When total pre-heating is adopted there is little danger of expansion cracks, provided that the heating is done slowly and uniformly, and that the object is well protected from draughts during the welding. A satisfactory pre-heating device is a furnace built up of fire-bricks around the casting, or object to be repaired, on the welding bench itself, the heat being provided by a coke or charcoal fire inside. When the whole is sufficiently hot the bricks immediately covering the parts to be welded are removed, enabling the work to be completed while the casting is still inside the furnace. This system would, of course, only be used for large castings, and for smaller work a muffle furnace is usually employed, although this necessitates the removal of the work from the furnace before welding, and is not, therefore, so satisfactory as the built-up furnace.

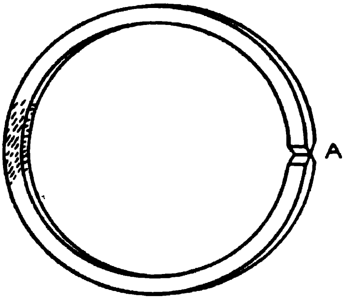


FIG. 32.—Local pre-heating as applied to a ring.

For local pre-heating a gas blow-pipe is satisfactory, care being taken to apply the flame longer upon thick parts than upon adjacent thin ones, so as to obtain as uniform a temperature rise as possible.

In pre-heating, a free use of asbestos should be made in the form of boards to shield the welder from the radiant heat, and in the form of wool to pack round the work, shielding it from draughts and reducing the rate of cooling.

The pre-heating temperature should obviously be as high as

it is possible to attain without damaging the work. The upper limit of pre-heating temperature is about 450° to 500° C., because above these temperatures the metal becomes soft and fragile, and is liable to collapse. This is particularly to be guarded against with thin walled castings, especially those made in an alloy of comparatively low melting-point such as the 11½ per cent. silicon alloy, and in certain cases it may be desirable to support the walls with sheet-iron propped in position.

In judging the temperature of pre-heating, the welder often makes use of dry sawdust which he sprinkles on the work while it is being heated. The sawdust begins to char at about 400° C. and pre-heating is stopped shortly after this point. The sawdust method is good in that it enables the welder to tell at a glance whether any one part is being heated more strongly than another.

Some welders judge the temperature by the sound given out by the work when struck, the sharp metallic ring giving place to a dull heavy note when the metal approaches the softening stage. Others stop pre-heating when the metal begins to sweat; and others judge the temperature by observing the wrinkling of the surface which takes place near the melting-point, or by pressing upon the metal from time to time with a piece of wood to determine the point where the surface begins to soften and feel plastic.

Finishing.

After the weld is completed the work should be allowed to cool very slowly, especially in the case of a complicated casting, and for such work arrangements should be made to extend the period of cooling to at least 24 hours. A convenient method is to cover up the work with sand, lime or asbestos, which has previously been warmed.

When the object is quite cool, and the excess flux has been washed off as previously described, it is beneficial lightly to hammer over the line of weld, when this can conveniently be done, taking care, of course, not to distort the work.

Welds in aluminium are quite often left untouched after completion, especially in the case of thin sheet metal, where the weld should be so even that it is not unsightly. When desired the line of weld can be made completely invisible by filing or grinding off the excess metal and afterwards polishing the whole.

An interesting point is that if the object is frosted after completion, the line of weld often becomes visible, even though before frosting there was no sign of it. The reason lies in the different physical condition of the metal at the weld, which results in a different rate of attack by the frosting solution. In frosted work, therefore, the weld will show up as a rather brighter ribbon in contrast with the rest, and when a matt finish is desirable on a welded article sand blasting is preferable.

CHAPTER VI.

OTHER JOINTING METHODS.

Soldering.

In the process of soldering advantage is taken of the fact that a metal of low melting-point when melted on the surface of a different metal of higher melting-point is often capable of forming an alloy with the unmelted metal. Thus, if tin is melted on a sheet of copper, the surface layer of copper will dissolve in the molten tin forming a thin layer of alloy, and a micro-graphic examination shows a variation in composition from pure tin at the top, through a whole series of copper-tin alloys of gradually increasing copper content, to pure copper at the bottom.

The first essential for a solder is that it shall readily alloy with the metal to be soldered, and the facility with which aluminium can alloy with zinc and tin suggests that the soldering of aluminium should present no insuperable difficulty. This is, in fact, the case, though the tough impermeable oxide film, present on the surface of even the most brightly-polished piece of aluminium, is an obstacle to free alloying which must be overcome. A further difficulty lies in the fact that the alloying does not take place effectively at the low temperature at which tin alloys with copper.

In autogeneous welding the removal of the oxide film is very satisfactorily done by means of a flux, but in soldering the temperatures are much lower, and it is by no means easy to find a flux capable of rapidly attacking aluminium oxide at a temperature well below the melting-point of the metal. It is a well-known rule that all chemical actions take place more

actively at high temperatures than at low, and while the alkali halide fluxes dissolve alumina rapidly at temperatures above 600° C. they are much less effective at the normal temperatures for soldering. On the other hand, in soldering, the time factor is not of such vital importance as in welding, and the flux can safely be given time to act. An alkali halide mixture, similar to that used for welding, but preferably mixed in such proportions as will provide a low melting-point, is, therefore, often used for aluminium soldering, and is quite effective provided that it is allowed to remain molten on the surface for a sufficiently long time. In practice this means that the ordinary soldering "bit" cannot be used, and that the soldering must be done by means of a gas blow-pipe or paraffin blow-lamp. Other fluxes sometimes used with aluminium have a stearin or resin base, but these have no dissolving action on the oxide, and the assistance which they give is limited to the provision of a molten covering which protects the surface from the air and hence prevents further action. Since they do not remove the oxide film originally present, effective soldering necessitates the use of a mechanical scraping action in addition, and it is doubtful whether their use is worth while.

Two distinct methods of soldering aluminium can be recommended. In the first, the two pieces to be joined are, after cleaning, painted with a water solution of an alkali halide flux and put together. A gas blow-pipe flame is played upon them until the flux is seen to melt, and the end of a stick of solder is then brought into use and melted on. The heating is continued, and in a few moments the globules of molten solder will suddenly spread out and run over the fluxed parts of the metal, effectively sweating them together. Some assistance to the spreading may be given by means of the solder stick, and it is desirable to continue heating for a few moments after the pieces are seen to be properly wetted with the molten solder. Excess solder can then be wiped away while the metal is still hot, and after the whole is set a very thorough washing is necessary to remove all excess flux.

In the second method no flux at all is used, and the two parts to be joined are first "tinned" separately. This is done by heating the metal strongly and then melting a little solder upon it. This will not adhere, but it can be made to do so by scraping it in with an old hack saw blade or other form of scraper. The oxide film is thus broken up under the molten solder, which itself protects the aluminium from further oxidation, and alloys with the metal at all points where the oxide has been scraped off. The scraping must be thoroughly well done, because the strength of the joint depends largely on the efficiency with which the oxide film is broken up, and it is a good plan, after an apparently even coating of solder has been obtained, to work this in by scratching with a wire brush.

When the two pieces are properly tinned they may be sweated together without further difficulty.

Solder Composition.

As regards ease of application the composition of an aluminium solder is not of great importance. The majority of solders consist of zinc-tin alloys, either alone or with the addition of small quantities of aluminium or copper. Good results are obtainable with an alloy of 35 per cent. zinc with 65 per cent. tin, and another common mixture contains 20 per cent. zinc, 70 per cent. tin, and 10 per cent. aluminium. In another class of aluminium solder the tin is replaced by cadmium, while in a third class the aluminium content is increased largely, and the other components are zinc and copper. A vast number of patents for special aluminium solders have been filed, covering the addition of bismuth, cæsium, silver and so on, but there is little evidence that such additions provide any noticeable advantage over the ordinary simple compositions. The soldering of aluminium can, in fact, be carried out with solders made up of mixtures of any of the metals known to alloy readily with aluminium, but in the choice of a solder consideration should be given to three factors—strength, melting-point and permanency.

The strength of an aluminium solder should, of course, be as high as possible, but high strength is of little importance if it is not accompanied by a fair degree of ductility. This warning is necessary because in attempting to evolve solders of a convenient melting-point one is apt to produce alloys within the mechanically fragile range, which will break if merely dropped on to a stone floor. The strength of a soldered joint is not greater than that of the solder itself, but even a weak solder can produce exceptionally strong joints if the solder film is not subjected to direct tension. Most soldered joints are lap joints, in which the solder is in shear, and the strength of the joint is directly proportional to the area of overlap. Tensile tests on lap joints form no criterion of the strength of a solder, for a lap joint with a weak solder can quite easily be shown stronger than a lap joint with a good solder if the area of overlap is not the same in both cases.

The melting-point of the solder should be high, because the necessary alloying with aluminium occurs more thoroughly at high temperatures, and it is, therefore, desirable to carry out the operation at a temperature as close to the melting-point of aluminium as is safe. When the solder has a high melting-point the worker is forced to use a high temperature in soldering or he will not be able to get the metal to flow, whereas with a solder of low melting-point a ready flow of molten metal will occur over the aluminium at a temperature which may be too low to provide proper alloying.

All solders with a zinc-tin base begin to melt at about 200° C., but the composition should be such that they are not completely molten before about 400° C. or more. In this connection a very excellent soldering material is the 12 per cent. aluminium-silicon alloy. This melts at about 580° C., which is somewhat higher than the melting-point of most aluminium solders, but is sufficiently below the melting-point of aluminium to give rise to little danger of melting the work. At the melting-point the silicon alloy combines very readily with aluminium, and it is, moreover, very fluid, so that it spreads quickly.

Electrolytic Action.

While the process of soldering aluminium presents no great difficulty, soldered joints are not recommended for important work because they are apt to deteriorate on exposure. It is a well-known fact that when two different metals are in contact, and are exposed to moisture, minute electric currents are set up as in a galvanic cell, and one or other of the two metals will rapidly corrode. This action is particularly pronounced when aluminium is one of the metals concerned, owing to its highly electro-positive nature, and the majority of aluminium solders differ sufficiently from aluminium in an electro-chemical sense to give rise to danger of galvanic action and rapid corrosion.

The point can be illustrated in a practical way by boiling a sample joint in water. It will usually be found that however strongly or well made the joint may have been to start with, it will fall apart of its own accord in a few hours, and it may be remarked that this end is attained even more quickly if a pinch of salt is added to the water. This same kind of deterioration proceeds on merely exposing a soldered joint to damp air, though naturally at a very much slower rate, and in consequence the boiling test can be taken as a means of judging the relative permanence of different solders. This test is, indeed, the most important to be applied to a solder, for as regards ease of application there is little to chose between the various solders upon the market, while strength determinations are rarely of any value. Specimens for boiling must, of course, all be of the same form and size, and a convenient standard is a lap joint between two strips one inch wide having a half-inch overlap. If such specimens will withstand boiling in distilled water for 60 hours the solder may be considered of good quality, but many of the solders placed upon the market fall away after five or six hours' boiling. The silicon alloy solder appears to stand out above all others as regards resistance to deterioration, and specimens have been boiled for over 200 hours without falling apart.

The presence of moisture is essential for galvanic action, so that a joint which is kept dry will be totally unaffected by age however poor the quality of the solder. It is, therefore, desirable that soldered joints should be painted or enamelled after completion, and many writers go so far as to recommend that no soldered joint should be used in conditions which will not permit of its being kept dry by this means. Though this is an excellent rule it cannot be denied that soldered joints have given entire satisfaction in circumstances where they would be expected to be useless. For example, manufacturers of aluminium kettles often adopt the process of soldering for fixing on the spouts, and the fact that they have but few complaints from their customers indicates that the soldered joint lasts for a reasonably long time. It is possible that the explanation for this unexpected result lies in the design of the spout, whereby the joint itself is largely protected from the action of the boiling water inside, and such examples should not be taken as in any way detracting from the statement that oxy-acetylene welding is preferable. Where soldering is considered essential, either by reason of cost or convenience, the silicon alloy solder is strongly recommended, unless, of course, the metal to be soldered is an aluminium alloy which would have a melting-point not sufficiently different from that of the melting-point of the silicon alloy solder to enable the latter to be used safely.

In point of fact it is desirable to avoid the use of solders in the repair of aluminium alloy castings, not because castings are more difficult to solder than pure aluminium, but because the process provides a means of repair which is liable to abuse. Small surface blow-holes often occur in places where their presence does not affect the value of the casting from the strength point of view, and such defects are sometimes hidden by filling in with solder. The process is simple, and an apparently good repair is easily made, but there is always a risk that the worker has not taken sufficient care to remove the oxide, and to obtain a good joint, so that the plugs of solder are apt to work loose and drop out under the vibration of normal

working. Unless the process of "casting-on" as described in Chapter IV. is adopted, the next best method is to drill out the defect, tap it, and screw in a plug of aluminium. If solder is used the hole should be under-cut so that the solder cannot work out, even if it loosens.

Soldering is sometimes applied for the building up of broken parts, or the filling of large holes in castings caused by accidents. In this process a piece of sheet-iron is wedged behind the hole, and the edges are heated until they soften and are then tinned with solder. Sticks of solder are then melted in to fill up the hole, and, the solder being kept in the pasty, semi-molten condition, it is worked into the right shape and the surface smoothed off. In this way an excellent-looking repair is possible, but the good appearance is its only attribute and the process is a thoroughly bad one. The added metal is considerably less strong than the original casting, the junction at the edges is unreliable, and the good initial appearance is not permanent, since the added metal has a tendency to blacken with age, even if electrolytic action does not set in. Repairs of this sort carried out by unskilled workers, with no attention to expansion or contraction effects, and little care to remove the oxide, are the cause of much dissatisfaction at what is sometimes described as "aluminium welding."

Pressure Welding.

While it is not impossible to weld aluminium by hammering in the same way that the blacksmith welds iron, the range of temperature within which such welding is possible is very limited, and it is extremely difficult to keep the temperature at the correct value for sufficiently long to enable the oxide to be worked out under the hammering. Hence this particular process has no value in practice, but the same principle is applied in a special form of welding in which the joint is made by simple pressure, and this has a wide application for the jointing of wires and rods.

In this process the ends of the rods to be welded are held

in the flame of a blow-lamp until the sharp edges are seen to be rounding off, indicating that the metal has begun to melt. During the heating the skin of oxide will thicken up to such an extent that it forms a tough retaining bag for the molten metal, so that even if a very considerable proportion of the metal at the end is melted it will not fall away. It is not necessary to carry the heating to this extent, however, and as soon as the edges begin to melt the blow-pipe is removed and the ends pressed firmly together. The pressure will burst the skin of oxide, which will be squeezed out with a mass of plastic metal, to form an irregular collar, within which the oxide-free metal solidifies to form a homogeneous joint. If the collar is trimmed off with a chisel or file no sign of a joint will be visible, and for all practical purposes the weld is perfect.

The process is employed for wires and rods of all sizes up to about 1½ inches in diameter. Wires up to 3/16-inch diameter can be welded by hand pressure, but for larger sizes some simple form of lever device is employed for pressing the ends together. Such a system can be seen in Fig. 33, which shows the welding of a number of aluminium electrical conductors on site. For very fine wires a little welding flux will assist, but this is not necessary, nor desirable, with larger rods.

The process is extremely simple and can be carried out by unskilled labour after a very little practice. A few preliminary trials are necessary for the worker to learn the best instant to stop heating and also to get the knack of pressing out the oxide cleanly. A slight rotary motion during the pressing will assist in this latter respect.

The ordinary plumber's blow-lamp is quite sufficiently powerful for the heating, though with the larger sizes of rod it may be necessary to employ two blow-lamps playing on the ends from opposite sides so as to obtain uniform heating. With rods up to about half an inch diameter a single blow-lamp is sufficient, with an asbestos or fire-brick backing erected on the opposite side from the blow-lamp so as to concentrate the heat at the back.

FIG. 33.—Making a butt weld between aluminium rods on site.

[To face page 136.

Care must be taken to keep the rods in alignment, and with small sizes one good method is to lay the rods in the V formed by placing two fire-bricks at right angles, a hollow being chipped out at the centre to permit the plastic metal to be squeezed out uniformly. Where the finished work is to be of definite length the original length of the rods should together be longer than the final required length by an amount equal to their own diameter.

Electric Butt Welding.

The two broad classes of electric welding used with iron and steel—resistance welding and arc welding—are both applicable to aluminium, though the results are not generally so satisfactory. The simplest form of resistance welding, which has been largely adopted for the jointing of steel wires, is, in modern day practice, a purely automatic process, and a large number of different designs of butt welding machines are upon the market. All of these consist essentially of an electric transformer capable of supplying a large current at a low voltage, the terminals of which are two heavy clamps or vices which hold the ends of the wires to be welded. One of these vices is fixed, while the other is arranged to slide in such a way that the wires can be pressed together. When the wires touch, the electric circuit is completed, allowing the current to flow through the butted joint, which becomes heated in consequence. The heat will be greatest at the point of highest resistance where the ends are in contact, so that these points will rapidly be raised to the melting-point, and, under the applied pressure, will fuse together.

The same form of machine is used with aluminium welding, and very consistent results are obtainable once the apparatus is adjusted to give the proper current strength, the proper instant of cut off, and the proper pressure. For this reason the most satisfactory type of apparatus for aluminium is that in which the whole action is automatic, the wires being pressed together with a predetermined pressure, and the current cut

off at a predetermined instant after the first contact is made. This is important, because with aluminium the whole process occupies only a fraction of a second, and with manual operation it is difficult to reproduce with exactitude the best conditions every time. The adjustment will vary for every different size of wire dealt with, and where a wide variety of work is undertaken the pressure butt weld made with a blow-lamp is probably more satisfactory. In the case of repetition work where, once the machine is adjusted, no alteration is necessary, the electric butt welding process is quite satisfactory, and is much more quickly done than the blow-lamp weld. The method also has the advantage that it is capable of making joints between aluminium and copper or other metals, but such joints are not very reliable, since the junction may contain sections consisting of brittle alloys of the two metals. Where the final joint is not to be subjected to stress, however, the possibility of being able to make a permanent weld between copper and aluminium is of considerable value.

It will usually be found that for aluminium welding the welding machine should be set for the lowest value of secondary current provided by the extreme transformer tappings, and that the pressure between the ends should be very small. Experiments will be necessary with various current strengths and pressures before the best conditions are found for any particular work.

A properly made electric butt weld has the same characteristics as the blow-pipe weld, the oxide being squeezed out in the form of a collar, which can afterwards be trimmed away.

Percussive Welding.

This very interesting process of welding was originated by L. W. Chubb, of the Westinghouse Electric and Manufacturing Company of Pittsburg, U.S.A., and while operating broadly upon the same principle as the butt welding process just described, it differs in regard to the nature of the current used. The current employed is the discharge of an electrical condenser,

the terminals of which are connected to the two parts to be welded, and arrangements are made whereby these can be brought together rapidly; the contact short-circuits the condenser, and thus causes an instantaneous discharge simultaneous with the pressure due to the percussion.

One form of the apparatus is made on the lines of a miniature pile driver, one of the wires to be welded being held in a carrier which, on releasing a trip, is arranged to fall between two vertical guides upon the second wire fastened to an anvil at the bottom. The height of fall is adjustable so that the force of impact may be varied to give the best conditions. The connections are simple and are shown in Fig. 34. In this A and B represent the falling and fixed carriers respectively,

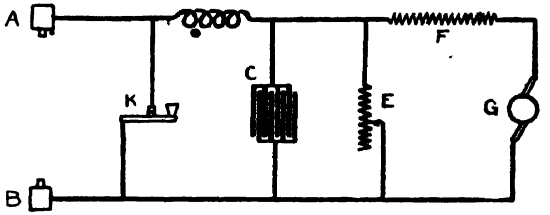


FIG. 34.—Electrical connections in percussive welding.

C is the condenser, which is of the electrolytic type, and G is the D.C. generator employed to charge the condenser. The charging current is limited by the high resistance F, and the variable shunt resistance E.

On opening the short-circuiting key K the condenser is charged, and the trip holding the movable carrier is then released, permitting A to drop until it hits B, and the energy of the condenser is discharged through the contact. Oscillograph records have been published * taken during the welding of No 18 B & S aluminium wires (0·04-inch diameter) which show that electrically the weld is complete in 0·0012 second, and though the current momentarily attains a value of 500 amps.,

* "Electro-Percussive Welding," by C. E. Skinner and L. W. Chubb, *Am. Electrochem. Soc.*, October, 1914.

the total amount of energy used is only of the order of one-millionth of a kw. hour. Since this energy is liberated in so small a time it will cause the fusion of only an exceedingly thin layer of metal, and to this is attributed the fact that welds made between copper and aluminium wires by this method are found to be quite flexible and ductile. Such joints have, indeed, been drawn down to a much smaller diameter without breaking. A further interesting point is that hard-drawn aluminium wires after welding are found not to be annealed, and it is suggested that this may be due either to the exceedingly small area affected, or to the hardening effect of the hammer blow.

The process is, unfortunately, limited to wires of comparatively small size on account of the large capacity required for the condenser, but it would appear to have a useful field for jointing fine instrument wires and for providing the finished coils of aluminium wire with copper lead-in wires which can more easily be soldered.

Spot Welding.

The process of spot welding is a type of resistance welding which is applicable to sheet metal, and in this a long seam is formed as a series of small welds, each of which is made on the same general principle as the electrical butt weld. While this process is also applicable to aluminium it is not very satisfactory where high strength is required, because it is difficult to clear the oxide film away, and the joint is apt to be brittle. In many cases this is of little consequence, but in general it can be stated that the welding of sheet-metal by electric resistance welding does not, at present, show any outstanding advantage over oxy-acetylene welding, and the latter is greatly preferred.

The different processes of electric resistance welding hitherto mentioned are all applicable to the ordinary aluminium alloys as well as to the pure metal, and, indeed, the welding of alloys, because of their higher electrical resistance, is often simpler.

Arc Welding.

Arc welding, in the case of iron and steel, is a serious rival to oxy-acetylene welding, but the arc welding of aluminium has not yet been adopted to any wide extent, though it appears to be capable of development. In the usual form of the process as applied to steel the seam is prepared as for oxy-acetylene welding, and the welder holds, in a suitable grip, a filling rod of iron. The work itself is connected to one pole of a generator (the negative pole if the supply be direct current) and the welding stick is connected to the other pole. To start, the operator momentarily touches the end of the seam with his welding rod and draws it back, thus forming an arc between the work and the rod. The intense heat melts the welding rod and the edges of the joint, and molten metal is carried down from the stick and deposited into the molten bath formed.

If such a process is tried out with aluminium, using an aluminium rod, it will be appreciated, from what has already been said, that no weld at all can be obtained. Every welding process, in order to be successful with aluminium, must incorporate some means of removing the oxide, and with the process just described the end of the welding stick would be melted and form a globule at the end, held in place by the skin of oxide. When the globule grows to such a size that it breaks away of its own weight, it will drop on to the molten edges of the work, but it will still be isolated by its skin of oxide, and when the whole has cooled the excess metal can easily be broken away with the fingers.

The obvious remedy is to use a suitable flux, but the flux cannot be applied to the work itself or it will prevent the arc from striking, and, moreover, the flux must be of such a composition that it is not easily volatilised. The temperature of the electric arc is much greater than that of the oxy-acetylene flame, but apart from this the conditions are much more serious than in the oxy-acetylene process in that in the latter the temperature of the metal is not raised much above the melting-point in spite of the high temperature of the flame, whereas in

the arc process a certain portion of the filling metal is vapourised and raised to the actual temperature of the arc. It is found that the alkali halide fluxes used in oxy-acetylene welding are too readily volatilised to be successful with arc welding, but it has been discovered by Mr. F. J. Heyes * that cryolite, either alone or mixed with a small proportion of an alkali chloride, is quite effective as a flux and remains fluid even at the high temperatures employed.

Cryolite is the natural double fluoride of sodium and aluminium which is used for dissolving alumina to form the electrolytic bath from which aluminium itself is electrolysed during the manufacture of the metal.

The cryolite flux is employed as a coating to the rod, and is first made up in the form of a paste of powdered cryolite mixed up with a 10 per cent. water solution of common salt. The paste may be sprayed on the rod by compressed air, or it may be applied by hand. In the latter case the method recommended is to make the mixture in the form of a fairly stiff paste which is spread out on an iron plate, and the aluminium rods are rolled backwards and forwards in this with the flat of the hand. If the paste is of the right consistency it will adhere to the rod and form a uniform coating which should be about one thirty-second of an inch thick. If necessary the paste may be bound on with cotton to prevent its ready detachment when dry. The paste must be quite dry before using the stick, and the pasted rods should be dried in a slow oven.

In carrying out the process the ordinary practice when welding steel should be adopted. The arc should be as short as possible so that the opportunity for oxidation of the falling molten metal is limited. This is assisted by the fact that the metal electrode melts away more rapidly than the flux, which, therefore, forms a small tube through which the molten metal can fall, away from contact with the air, as shown in Fig. 35.

* British Patent No. 150,372, 1919.

As in oxy-acetylene welding, the beneficial effects of pre-heating are marked, and when the work is pre-heated to about 400° C. the current required may be less than half of that required when the work is cold. The current consumption is rather higher than that for welding an equal thickness of steel, owing to the heat-conducting power of aluminium. As an example Heyes gives the requirements when using a quarter-inch plate with a No. 8 s.w.g. filling wire as 150 amps. with the work cold, whereas with a similar thickness of steel the current necessary is only about 80 amps. under the same conditions. With pre-heated aluminium plates the current required is only 60 to 80 amps.

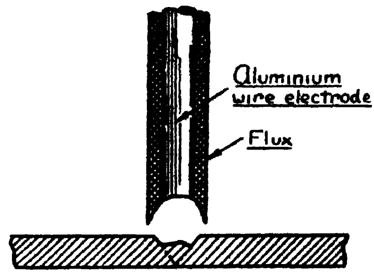


FIG. 35.—Electric arc welding of aluminium.

Riveting.

Riveting is largely employed for sheet metal where a water-tight joint is not essential or where, as in the case of duralumin, welding would not be permissible. Riveting is always done cold, and the rivets should be of the same metal as the sheets to be joined, for the reasons previously explained. Duralumin rivets should not be used in the annealed condition, since they cannot normally be heat-treated after the work is done. They are usually supplied in the " normalised " or final heat-treated condition, and for the majority of applications they can be used in this state. If signs of cracking are observed in the rivet-head on hammering up, it is necessary to carry out the normalising process on the rivets immediately before use, in the manner previously described. Immediately after quenching they are soft and can readily withstand the deformation of riveting, and after the work has been done the rivets will then age-harden *in situ*.

Aluminium rivets should be a fairly loose fit in the holes because they spread easily, and they should be set well back from the edge of the sheet because the sheet itself is apt to spread under the hammering. The result is an unsightly waving of the overlapping edges, as shown in Fig. 36. A further point to be guarded against is spreading of the sheets in the direction of the line of rivets, causing the holes to get out of coincidence, as is also indicated in Fig. 36. This can be obviated firstly by spacing the rivets fairly wide apart, and secondly by putting in the rivets indiscriminately along the whole length instead of commencing at one end and proceeding progressively.

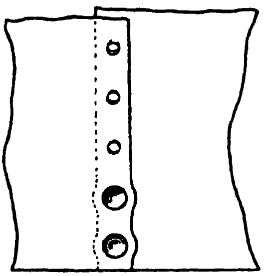


FIG 36.—Simple riveted joint showing spreading of the metal.

Aluminium rivets should have large heads, particularly when they are used for jointing aluminium sheet to other metals. The rivets used for fastening a steel handle to an aluminium saucepan, for example, will readily tear out unless the heads are large in diameter. Countersunk rivets are sometimes used to ensure a flat surface, but these are not very satisfactory with sheet metal because of the limited bearing area available. Where countersunk rivets are used it is very necessary to see that the angle of countersinking in the sheet shall be the same as that of the rivet. It is a good plan also to attach a gauge to the side of the countersinking drill to fix the depth of countersinking at the correct value necessary to bring the head of the rivet to the level of the surface of the sheet.

Panel Joints.

The joints between sheet aluminium panels in a motor car, if not made by welding, are arranged to occur at a door-post or other upright in the frame of the body, and the junction is hidden under an aluminium moulding which is fastened down by screws. If the screws cannot be put into the moulding

from the back, they can be effectively hidden from view by forming the hole in the moulding with an upstanding burr which can afterwards be hammered down over the screw head. One method of forming the hole is shown in the series of operations illustrated in Fig 37. The first process is the use of a die and punch, the punch having a diameter a little larger than the screw shank, and the hole in the die being sufficiently large to allow a good thickness of metal to be punched up, as shown at A. For thin mouldings the punch illustrated will be quite satisfactory for making the hole itself, but for thicker metal it

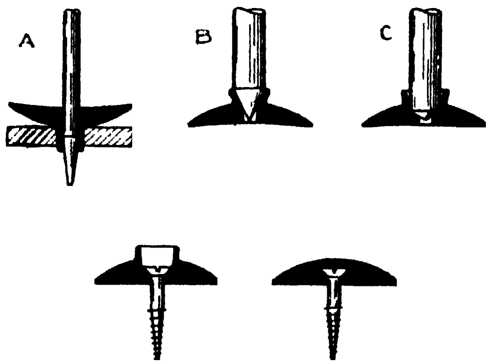


FIG 37 -Stages in the formation of an invisible panel joint.

may be necessary to drill a pilot hole first. The next operation is the use of a drifting punch, as shown at B, and the hole is finally made ready for the screw by the countersinking punch shown at C. After the screw has been driven home the burr is gently hammered over, and if carefully done the surface of the moulding will show little sign of the presence of the screw.

Mouldings are usually made with a slightly concave undersurface, as indicated in the sketches, so that when the screw is driven home the edges of the moulding press very tightly on the sheets and hold them firmly.

CHAPTER VII.

SHEET METAL WORKING.

Press Work.

Aluminium is far more ductile than steel or brass in the sense that it can withstand considerably greater deformation before reaching the stage when breakage, due to excessive hardening, is likely. Thus, in pressing a deep shell in steel or brass, frequent annealing operations are necessary, and sometimes, indeed, annealing is required after every operation in the press. With aluminium, on the other hand, it is often possible to submit the metal to four or five reducing operations without any annealing whatever. Moreover, when annealing is necessary it can very simply be done by immersing the shells for a few minutes in a bath of oil maintained at about 330° to 350° C., and, after removal and cooling in water, they can be returned to the press for further working without any pickling or scaling process. Only a very few minutes exposure to the annealing temperature is required, so that the process can be arranged as a continuous one, a stack of shells, in a suitable tray, being left in the bath only during the time required to prepare the next stock. An alternative liquid bath is molten lead, which has the advantage that it gives off no fumes and also that it does not *wet* the aluminium, so that no draining or washing operation is required.

The power required for press working with aluminium is substantially less than that for other metals, and in blanking, for example, the force required is less than one-half that necessary for an equal thickness of mild steel. A press designed for any

particular maximum thickness of steel can, therefore, quite safely be employed for cutting twice that thickness in aluminium. The point is illustrated in Fig. 38, which shows the maximum capacities of presses of different ratings. In this

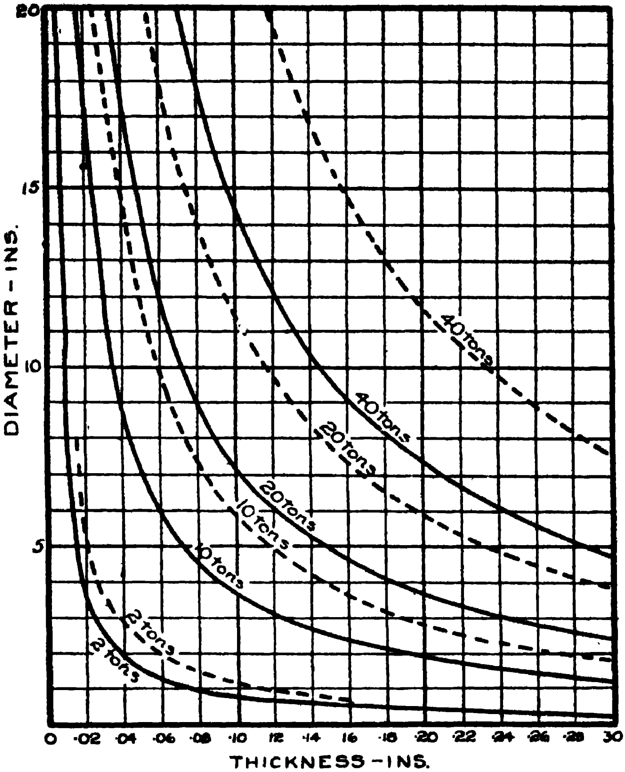


FIG. 38.—Maximum cutting capacity for blanking presses on aluminium. (Plain curves for straight dies, dotted curves for dies with shear.)

the metal referred to is hard drawn, so that even thicker metal might be cut if the temper were softer.

Apart from these points the practice with aluminium is no different from that with brass or steel. The same types of press and same kinds of die are employed, though in finishing the dies it is necessary to take special pains to obtain bright

clean surfaces, and to maintain the dies in perfect condition, because aluminium being soft will be marked by small surface irregularities which would be negligible when dealing with harder metals.

In this connection the proper choice of lubricant will greatly facilitate the work. Aluminium should never be worked dry, and for deep drawing a thick lubricant such as vaseline or heavy machine oil is best. For shallow stampings or for blanking, a lubricant is not so essential, but the use of paraffin oil is, nevertheless, recommended because it provides a cleaner cut and at the same time prolongs the life of the tool and assists in stripping. When the blanks are cut from rolled strip a convenient method of supplying the lubricant is to run the strip through a bath of oil as it is fed to the dies.

In applying the lubricant for deep drawing the usual method is to paint the blanks with a brush or wipe them over with a pad. In this way the lubricant is not applied to the centre of the blank, which is not worked, and, therefore, does not need lubrication, and the oil is used economically. The practice is not economical in time, however, for it is necessary to lubricate both sides of the blank, and the time required may, therefore, constitute a substantial part of the total production time for the finished article. A method by which both sides may be lubricated at the same time is to pass the blanks through a pair of felt-covered rollers, which are first saturated with oil. Rollers covered with felt ¼-inch thick will hold sufficient oil to lubricate several thousands of blanks. Re-charging may be done by passing through the rollers from time to time a blank which is first thickly coated with oil. The use of rollers will provide a thin film of oil all over the blank which will disappear during the working, so that subsequent cleaning is not necessary. In other cases excess of grease is washed away with paraffin or petrol.

The temper of the blanks should be so chosen that the work-hardening which takes place during the drawing will result in the finally shaped article being hard and rigid. The

greater the deformation which the metal has to undergo, the softer should be the initial temper, and while a shallow stamping can be done on medium hard blanks, deep drawing requires the softest available temper to commence with. Where the metal is thin it is good practice, after the bulk of the shaping has been done, to pass the blanks through dies designed to "iron" the metal, i.e. to reduce its thickness slightly without much alteration in shape. This is a very effective hardening operation which leaves the metal very uniform in thickness and with a fine, smooth surface capable of taking a high polish. The amount of thickness reduction allowable may be appreciably greater than that usual with iron, but usually ·003-inch to ·004-inch is sufficient for all metal thicknesses.

In planning the number of operations and the form of the intermediate cups necessary for the production of any final shape, the designer must give consideration to the thickness of the metal and to the form of press available. With a double action press in which the blank is held rigidly during the drawing, the amount of reduction per operation can be very much greater than that with a single action press, where the danger of wrinkling is much more pronounced. Under the best conditions, using a double action press with dies of the forms shown in Figs. 41 and 42, the diameter of the first cup can be from 50 per cent. to 60 per cent. of the blank diameter, and in the subsequent re-drawing operations the percentage reduction in the diameter of the cups can be about 25 per cent. Smaller reductions would be desirable with dies of the simple "push through" type, or if the shell is tapered, or if the metal is "ironed."

These points may be illustrated by a special case such as the tapered cup shown at D in Fig. 39. This is to be produced from a 5⅜-inch blank, initially 0·036-inch thick, but reduced during the working to 0·028-inch. The general procedure will be to draw a series of straight-sided cups until the last operation of all, where the taper will be given, and hence it is evident that the last cup but one must be a shell about 2⅜ inches diameter, as shown at C.

It will be convenient to arrange that the dies in which cup C is produced will also do the ironing, and since ironing will itself involve a very considerable pressure on the bottom of the shell during the drawing, it would be inadvisable to arrange for any large diameter reduction at the same time. Hence the diameter of the cup preceding cup C should not be greatly different, and a suitable value would be 2½ inches. This will almost definitely fix the diameter of the first cup A as 3⅛ inches, which is 55 per cent. of the blank diameter, and gives a percentage reduction in the second operation of 20 per cent.

The heights of the various cups are, of course, fixed by the

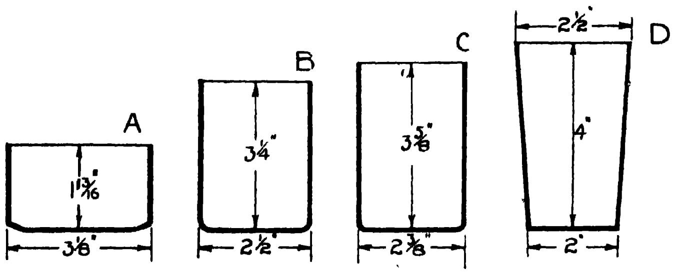


FIG. 39.—Stages in the pressing of a tapered cup.

amount of metal in the blank, it being assumed that no trimming is done during the working.

It is interesting to note that even if no ironing operation were required, it would still be necessary to employ four drawing operations for the production of this cup. If both blank and finished cup are of the same thickness, then the requisite blank diameter would be 6⅜ inches, and it would be found impossible to get down from this diameter to the dimensions of cup C with only one intermediate operation, without greatly exceeding the normal limits of diameter reduction.

In contradistinction with this simple case, interest is attached to Fig. 39A which shows the stages in the production of an aluminium funnel. This is a one-piece article drawn from a blank initially 200 mm. dia. and 0·8 mm. thick, the

final thickness of the metal after formation being 0·5 mm. A special feature of the successive operations is the manner in which the very severe deformation of the central portions of the initial blank is spread over a series of easy stages, the sections being bevelled to an angle of 45° with large radii at the corners. A full description of the dies employed in this

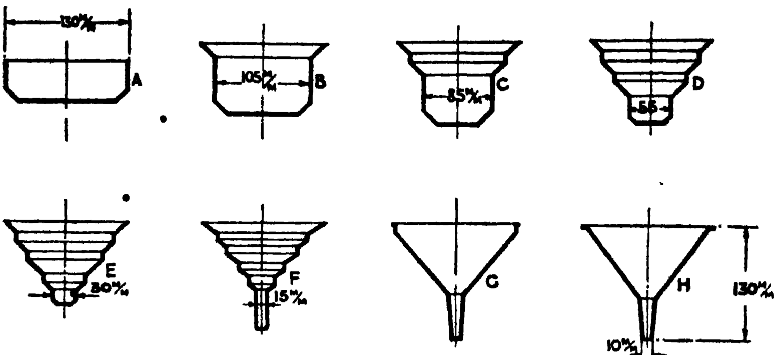


FIG. 39A.—Stages in the pressing of an aluminium funnel.

work is to be found in *Pratique des Industries Mécaniques* for May, 1926.

Dies.

Blanking punches for thin stock in aluminium are often made of mild steel without case hardening, and such tools are capable of giving a life of 70 to 100 working hours without attention. When the edges lose their keenness the punch is upset by hammering, and, after oiling, it is forced into the die hole and the excess metal sheared off. In this way the edges are kept sharp and the life of the punch can be renewed indefinitely. The process is simple and economical when the number of blanks required is comparatively small. For thick metal or for a very large number of blanks the punch is best made of tool steel, and this may be left soft, since aluminium is so much softer that wear will be very slight. Hardening always introduces a risk of distortion or breakage in use, and its avoidance where possible is desirable. The dies for blanking

are made of tool steel carefully hardened, but the cost can be minimised by making the body of cast iron with a tool steel inset.

The angular clearance for a blanking die is 2 to 5 degrees, i.e. the walls of the opening through which the blank falls should expand away from the cutting edge at the rate of 1/16-inch to 3/16-inch of diameter per inch of depth. Clearance between punch and die opening is necessary unless the work is thin, and for aluminium the amount of clearance can be taken as one twenty-fifth of the stock thickness. Thus, for blanking stock of ⅛-inch thickness the punch diameter should be 0·005 inch smaller than the die opening. When punching to exact size it may be taken that the blank will have the diameter of the die, and the hole left in the stock will have the diameter of the punch. Thus, for blanks which are to be 4 inches diameter the die opening is made exactly 4 inches diameter and the clearance is taken off the punch; when punching holes which are to be true to size the punch is made to the exact size, while the clearance is added to the diameter of the die opening.

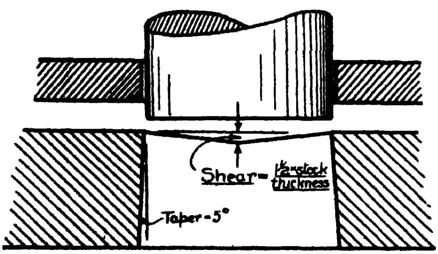


FIG. 40.—Shear on a blanking die.

For cutting thick stock the power required can be minimised by giving shear to the die, i.e. by arranging that the tool surfaces shall slope towards the centre, as shown in Fig. 40, the amount of shear being equal to about 1·5 times the stock thickness. The objection to this practice is that the stock is distorted and this may lead to difficulty in stripping. The practice is, however, a useful one for enabling the cutting capacity of any particular press to be increased, and the amount of extra thickness possible is indicated by the dotted lines in Fig. 38.

For drawing deep cups the metal may either be purchased in the form of circular blanks of the correct diameter, or the raw material may be purchased as strip and the blanking and first drawing be done in one operation with double action dies. Which of these two methods will be the more economical depends upon the price obtainable for scrap. If circles already cut are purchased, no scrap has to be dealt with, but the metal costs more per lb. If the metal is purchased in the form of strip the cost is less per lb., but a fair proportion of the metal purchased is scrapped. Most usually for producing large-sized pressings, such as cooking utensil bodies, the purchase of ready cut circles is considered preferable.

The usual form of the dies is shown in Fig. 41, in which,

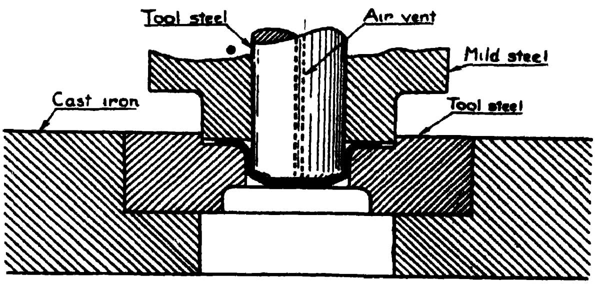


FIG. 41.—Typical first operation drawing dies.

as will be seen, the punch and die are of tool steel, the die itself being set in a cast-iron die-holder. Both punch and die are hardened, but the blank-holder can be of mild steel left soft.

An important detail is the radius of the edge of the die over which the metal is drawn. If this is too sharp the metal is stretched excessively and may be torn, while if the radius is too large wrinkling will occur at the top of the cup when the metal leaves the edge of the blank-holder and is no longer supported. It is good practice to make the radius about eight times the thickness of the stock.

The stripping is done by the under-edge of the die, which must, therefore, be kept sharp and re-ground from time to time.

Stripping is facilitated by keeping the punch exceptionally well polished—a precaution which is necessary owing to the tendency of aluminium to cling tightly rather than to spring out slightly as in the case of more rigid metals. It is usually desirable to provide an air vent as indicated.

The form of reducing die shown in Fig. 42 is used for thin stock and involves the use of a double-acting press. If the stock is fairly thick, the inside blank-holder may be dispensed with, though the tendency for wrinkling makes it desirable to use smaller diameter reductions per pass. The angle of the bevelled part of the die varies from about 30 degrees to the vertical for thick stock to 60 degrees to the vertical for very thin stock.

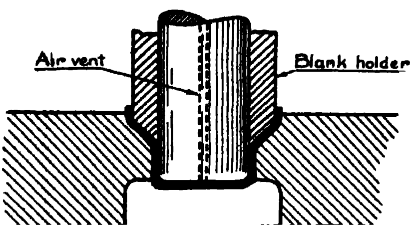


FIG. 42.—Typical re-drawing dies.

In all drawing dies the clearance between punch and die should be greater than the stock thickness owing to the tendency for the metal to thicken up at the top as it passes through. Unless allowed for, this thickening results in heavy stresses being thrown upon the lower portions of the cup during the drawing, and bursting may result. The clearance must not, of course, be too large or it will result in an uneven surface, and a good rule is to make the punch diameter less than the die diameter by 2·4 times the stock thickness. When a uniform thickness throughout is essential, the dies may be arranged for ironing, the lower part of the die being given a slight taper, and the clearance between punch and die at the lowest edge need then only be one or two thousandths of an inch greater than twice the stock thickness.

Blank Diameter.

The determination of the diameter of the blank required for any particular form of finished cup is usually made by

assuming that the surface area of the finished work will be equal to that of the blank. This is not strictly the case, since during the working there will usually be an alteration in the wall

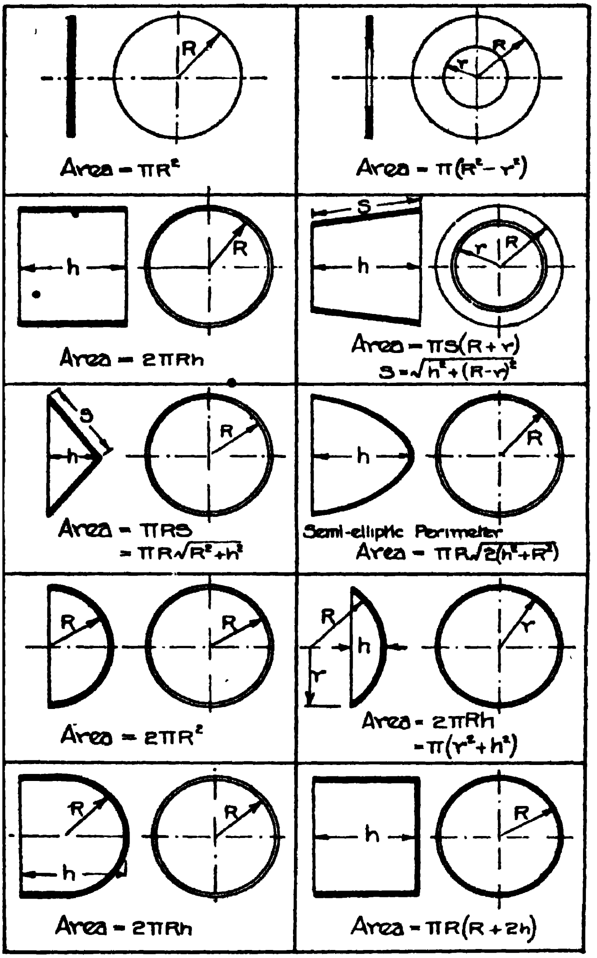


FIG. 43.—Surface areas of common shapes.

thickness, either a thickening up at the edges, or a thinning due to ironing. Allowance may readily be made for ironing by estimating the area of the shell at the final thickness and

multiplying by the ratio of the final thickness to the initial thickness to obtain the blank area. An even better method, when practicable, is to make up one article, from a trial blank,

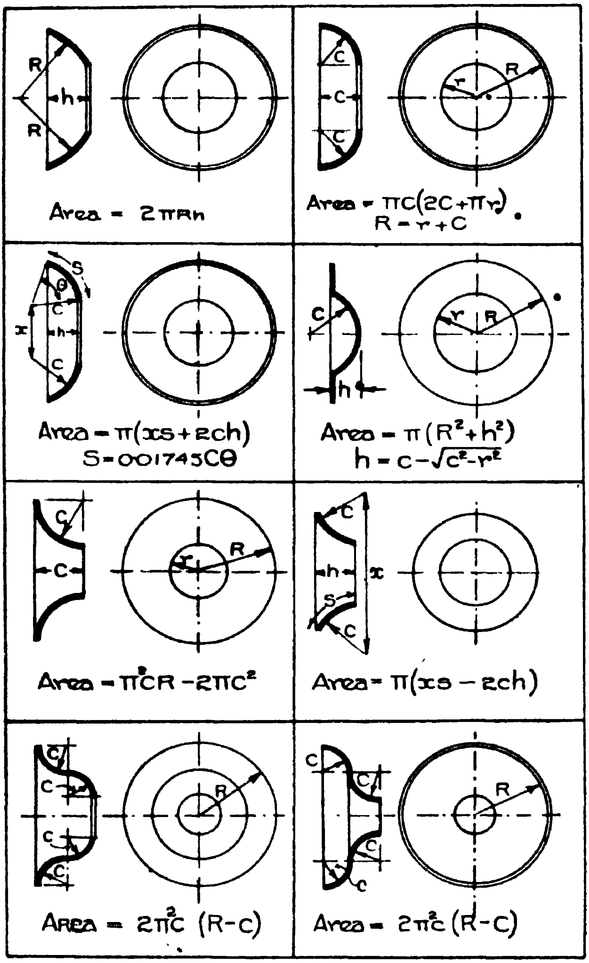


FIG. 44.—Surface areas of common shapes.

in the dies which will eventually be used, to trim to the height which is desired, and then to weigh the finished cup. If t is the thickness of the blank in ins. and w is the weight in lbs.

of the finished article in aluminium, then the diameter of the blank in ins. is given by the expression,

$$D = 3{\cdot}61\sqrt{w/t}.$$

In estimating the area of a cup from its shape the procedure is to divide it into a number of elemental forms of which the area is readily calculated from a mathematical expression. A selection of the more usual elementary forms is given in Figs. 43 and 44, which also include certain combinations of shapes for which simplified expressions are obtainable.

The use of the formulæ given can be illustrated by considering the special shape shown in Fig. 45. This has been divided

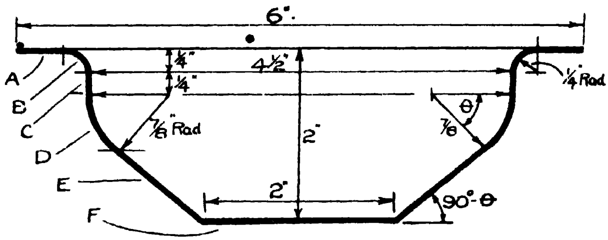


FIG. 45.—Shell divided into elementary geometric shapes.

into six sections lettered in the diagram A to F, each of which corresponds to one of the elemental forms given in Figs 43 and 44. The calculation of the total area is straightforward, except in the case of section D, where it is necessary to determine the length of the curved surface and also the height of the section. The best method is to draw the shape out to scale, measuring the height directly and calculating the length of the curved surface from the measured value of the angle θ. The angle θ is, incidentally, equal to 90° minus the angle between sections F and E at the bottom, as marked, so that a check is obtainable on the measurement. In the particular case illustrated h is found to be 0·65 inch and the angle θ to be $48\frac{1}{2}°$, so that s is calculated to be 0·74 inch.

The calculation of the total area then proceeds as follows:

Section A :	$\pi(R^2 - r^2)$	$\pi(3^2 - 2{\cdot}5^2)$	$= 8{\cdot}65$ sq. ins.
,, B :	$\pi^2 cR - 2\pi c^2$	$= \pi^2 \times {\cdot}25 \times 2{\cdot}5 - 2 \times \pi \times {\cdot}25^2$	$= 5{\cdot}77$,,
,, C :	$2\pi Rh$	$= 2\pi \times 2{\cdot}25 \times {\cdot}25$	$= 3{\cdot}53$,,
,, D :	$\pi(xs + 2ch)$	$= \pi(2{\cdot}75 \times {\cdot}74 + 2 \times {\cdot}875 \times {\cdot}65)$	$= 9{\cdot}98$,,
,, E :	$\pi s(R + r)$	$= \pi \times 1{\cdot}28\,(1{\cdot}96 + 1)$	$= 11{\cdot}90$,,
,, F :	πR^2	$= \pi \times 1^2$	$= 3{\cdot}14$,,
		Total	$= 42{\cdot}97$ sq. ins.

The diameter of blank required is found either by means of a table of circle areas or from the formula,

$$\text{blank diameter} = 1{\cdot}13\sqrt{\text{area}}.$$

In this case the diameter of the circle corresponding to 43 sq. ins. is found to be $7\frac{1}{2}$ inches approximately.

In the calculations no allowance has been made for the wall thickness, which is negligible in comparison with the diameter measurements, so that this practice will not introduce any important inaccuracy. When the wall thickness is of the order of 1 per cent. or more of the shell diameter, it may then be desirable to take all dimensions to the mid-thickness of the walls, as this will give the blank diameter to greater accuracy.

Spinning.

Spinning is one of the oldest of the sheet-metal working processes, and though, for repetition work, it has largely been superseded by press working, it still remains a useful process for certain special applications. For example, the cost of dies for press work is heavy and would not justify the use of the press for articles required in small number, whereas the chucks necessary for spinning can be made for much less cost. Spinning also provides a means of economically obtaining complicated re-entrant forms which could only be produced on the press with considerable difficulty, and a still further special application of the spinning lathe is the production of extremely large work, the manufacture of which, in a press, would be practically out of the question. Examples of such work are shown in Fig. 46.

FIG. 46.—Aeroplane engine cowls spun in aluminium.

[To face page 158.

FIG. 47.—Miscellaneous spinnings in aluminium.

[To face page 159.

The spinning lathe also plays an important part as an accessory to the press. Articles which have been produced by several press operations will have a slightly irregular edge, and if a lathe is available the trimming of the edge can be very effectively and rapidly done by this means. Trimming can, of course, be done by a special pair of trimming dies in the press, but this method is not usually so satisfactory. Small surface irregularities formed in pressing (slight wrinkling, for example,

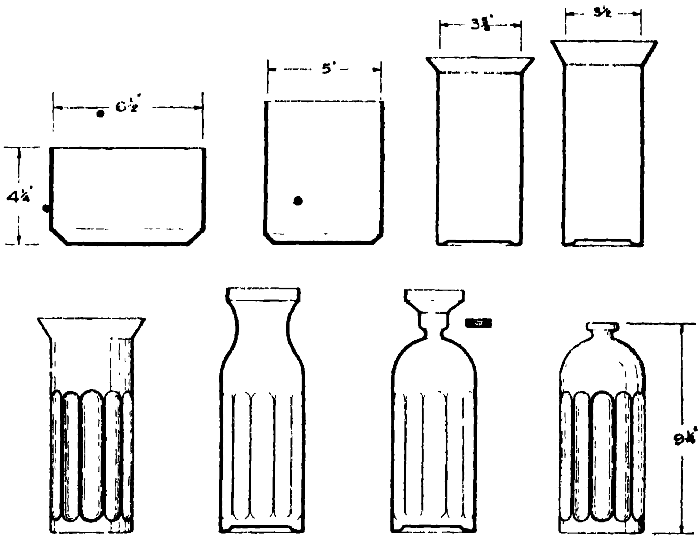


FIG. 47A.—Stages in the production of an aluminium hot-water bottle. (The London Aluminium Co., Ltd.)

which often occurs on tapered work), can be smoothed out by planishing on a spinning lathe, while articles which have to be necked or grooved, even if required in large quantities, can most easily be produced by first pressing as closely to the shape as possible, and then putting in the final shape on the spinning lathe. A selection of articles formed by a combination of pressing and spinning is shown in Fig. 47, which also shows examples of work (the military water bottles), which are first spun and afterwards flattened in the press.

Fig. 47A shows stages in the production of an aluminium article involving preliminary shaping in the press followed by final forming on the lathe. An interesting feature is an insertion of a screwed mouthpiece which is held firmly by spinning the sheet metal around it.

In the spinning process a former or "chuck," shaped to the interior form of the article, is rotated at high speed in a lathe. The blank is held against the end of the former by a wooden holder carried in the tail stock of the lathe, the back centre being arranged to rotate. The general arrangement is shown in Fig. 48, in which the back centre is shown provided with a ball bearing.

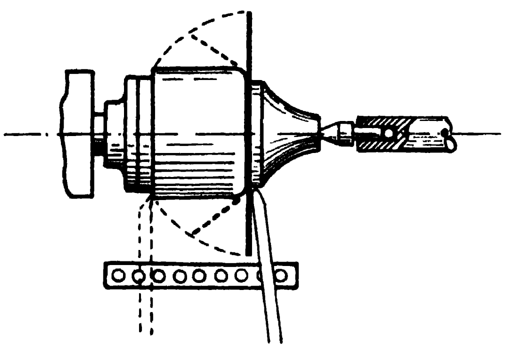


FIG. 48.—Ordinary method of spinning

The blank rotates with the chuck, and the worker forces it round to shape by pressing with hand tools with a lever action pressing on a pin in a tool rest. As the blank is forced down to shape the fulcrum is moved along, the spinning rest being provided with a series of holes for the purpose. When the blank finally fits the shape of the chuck, the edge is trimmed by a diamond-shaped cutting tool as indicated, and, without stopping the lathe, the back centre is withdrawn, the shell slipped off, and a new blank put in place for the next cup.

The amount of shaping which the metal can withstand is remarkable, and certain of the examples shown in Fig. 47 illustrate this point. In the background, for example, is shown a shell 24 inches high × 8 inches diameter spun from a flat blank 24 inches diameter, and more towards the foreground is a cake mould in which the metal has been turned over completely upon itself. Spinning has the advantage over press

work, where such extreme distortion is necessary, in that the worker can feel by the way the metal flows under his tool when hardening has occurred to such an extent that annealing is desirable, so that burst or torn work is a rarity. As in press work, annealing is rarely needed, and the majority of commercial articles are completely finished on one chuck without a stop. When annealing becomes necessary the usual method is to play a blow-pipe on the work, sometimes without removing it from the lathe, judging the temperature by the readiness with which the metal chars a dry match stick rubbed on its surface.

The blanks used are lubricated during the work with a thick machine oil or vaseline, applied by means of a rag. The tools used must be finished with very smooth surfaces, and are usually of tool steel heated at the end and quenched, without tempering, so that the working faces are almost glass hard while the shank is comparatively soft and hence not liable to crack. The working surfaces are kept well polished by occasionally rubbing them on a strip of leather glued to a piece of wood and sprinkled with putty powder.

The spinner commonly develops his own ideas on the form of tool, and each man usually has special forms of his own design. There are, however, certain tools which are used to some extent by all spinners, and a selection is shown in Fig. 49.

The round-nosed tool, which is usually about 1 inch diameter, is the most used of all tools, and is the one almost always chosen for commencing. The "raising up" tool is used for dishing concave towards the lathe head, and the lobes on either side may be used for forcing the metal into an under-cut lip. The "turning over" tool, made of ½-inch round steel, is used for convex surfaces, and also, if the semi-circular back of the flat face is polished, it can be used to form the radius of a flange. The "knob raiser" is used for concave dishes or for forming a wide groove in the periphery. Narrow grooves are formed by the "groover," which is used by placing the end under the work and pressing the handle downwards, the tool rest acting as a fulcrum. Owing to the shape of the tool, grooves of

different widths can be formed by varying the point at which the end makes contact with the work. The planishing tool is used for smoothing or burnishing and is also applied to the under-side of the work, using the tool rest as a fulcrum. The trimming tool is similar to the wood-worker's diamond point

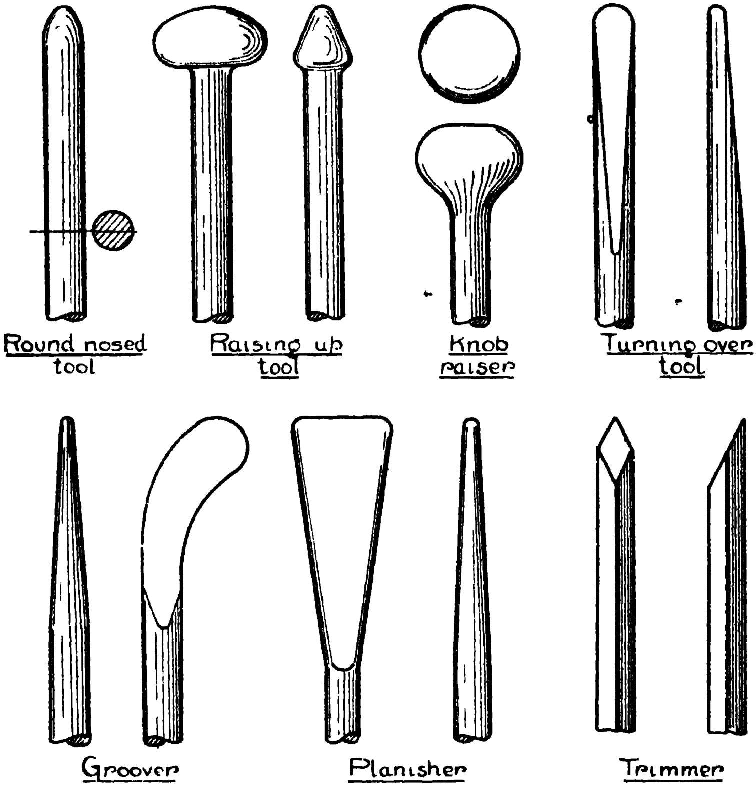


FIG. 49.—Various spinning tools.

tool, and is used in the same way, i.e. by applying it to the work on the dead centre so that the edge is cut off in shavings.

These various tools with their handles are usually 24 to 30 inches long, the handle itself being about half this length, and in use the worker supports the handle under his armpit so as to

make use of the whole weight of his body. The handles must be of good quality wood and the steel shank must be fitted in very efficiently, because the loads thrown upon the tools are heavy, and any failure during the working may result in a serious accident.

The chucks are usually of hard wood, the best being lignum vitæ or boxwood, both of which are very hard and capable of being formed with a very smooth surface. For less important work beech has been used. The chucks are sometimes of aluminium or of zinc, which are rough cast to shape and afterwards finished by turning with hand tools. Where the number of articles required is large, iron chucks can be used with economy.

Chucks for forming re-entrant shapes, such as that shown in Fig. 50, are sometimes made in sections in such a way that

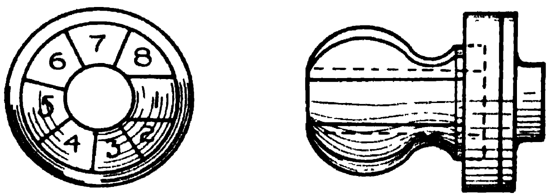


FIG. 50 —Sectioned collapsible chuck for spinning re-entrant form.

after the spinning is completed the chuck may be withdrawn piece by piece. In the example shown the chuck is divided into eight sections which fit together round a central peg projecting from a recessed holding plate carried by the head-stock of the lathe. When the work has been spun on this chuck, the back centre is withdrawn, and the work, enclosing the sectioned pieces, is pulled off from the holding plate. As the central peg remains behind, the various sections can be removed easily, section No. 1, which is the key piece, being removed first, followed by the other sections one by one in the order indicated.

Sectional chucks of this kind have to be well made, or the junctions between the sections will make it impossible to obtain a perfect surface on the finished work. An alternative process

is "spinning on air" in which a straight-sided shell is first spun in the ordinary way, and the final form is obtained without a shaped chuck. The worker uses his tools on the outside of the shell in the ordinary manner, but supports the inside by means of a wedge of hard wood held in his left hand. The process is difficult, but a skilled worker can manipulate the metal with almost the facility with which a potter moulds his clay, and further, by the use of a template, the finished work can be turned out remarkably true to size.

The lathes used for spinning are similar to wood-working lathes, but the head-stock bearing must be large and must be fitted with a very efficient thrust bearing, because of the heavy pressure upon it. The tail-stock should have a long travel, and the screw should have a coarse pitch in order that the shell, after spinning, can be rapidly withdrawn.

The chuck should be driven at a linear speed between 3000 and 4000 feet per minute, so that for work of 6 inches diameter or less the speed should be at least 2000 r.p.m.; for work between 8 inches and 10 inches diameter 1500 r.p.m.; for 12 inches to 15 inches diameter 1000 r.p.m.; and for 16 inches to 20 inches diameter 750 r.p.m. This variation in speed is usually obtained by means of stepped pulleys, but a preferable method is to employ an independent variable speed motor for driving each individual lathe, since this gives a much finer gradation in speed. For deep spinning this is particularly desirable, because the blank diameter will then be very much bigger than the finished diameter, and it may be desirable to change speed during the working down. The motor should be of the D.C. shunt-wound type, with a small amount of compounding. With the individual motor drive it is desirable to be liberal in selecting the motor size, and a 2 h.p. motor would not be excessive for work up to about 8 inches diameter, in metal not exceeding No. 14 s.w.g. thick. With a lower rating there is a possibility that with the heavy leverage developed by the tool, the spinner may pull up the motor during the work, resulting in a blown fuse, or a burnt-out winding. For light

work, up to 6-inch diameter in metal of 18 s.w.g., a 1 h.p. motor is quite satisfactory.

The blank diameter is determined in the same way as for press working, though the assumption that the blank area will be the same as the surface area of the finished work is not quite so accurate, since in spinning there is a tendency for the more heavily worked parts to be thinned down. The corners between the sides and bottom of a simple cup, for example, are apt to be thinner than the rest of the metal, and this thinning is sometimes claimed to be an advantage in that it leads to economy of metal without weakening the cup at the lip, where rigidity is most desired. Unfortunately, this practice can be carried to excess, and a bad workman will turn out work in which the corners are reduced to almost paper thinness and are liable to tear readily.

Panel Beating.

When hollow curved forms are required, too large, too irregular, or too complicated for press work or spinning, they may be formed by hammering from a flat sheet, and this process is much used in motor body building for the attainment of stream line shapes and graceful body outlines.

The "workability" of aluminium is such that practically no shape is impossible of attainment, and forms almost impossible with steel can be produced with comparative ease.

Though, as in many practical processes, the underlying principle is simple, panel beating is a highly skilled trade, not to be successfully undertaken without much practice, and the beginner must start with very simple forms and graduate through successively more difficult work, before he can hope for success with the more complicated shapes for which the process is chiefly valuable.

Two methods of working are used, either the shape is formed by hammering on a well-stuffed leather sand bag, or by hammering over a block of wood hollowed out to approximately the shape required and covered with a thickness of leather.

Sometimes both methods are adopted, the work being started on a sand bag and finished on the block.

The sheet employed is usually dead soft in temper, and it is first cut out to size with hand shears. The shape and dimensions of the sheet required for producing a complicated form cannot be found by calculation or by simple draughtsmanship, and it is often difficult to estimate the best dimensions for the initial sheet. Trial is then the only method, a trial sheet of metal being cut out with dimensions well above the probable requirements, and a paper pattern is kept of this initial shape. When the work is finished, pieces are trimmed off the paper pattern equal to those it is found necessary to trim from the shaped article. The next article made from a sheet cut to the modified pattern should require much less final trimming, but a further modification of the pattern may be found necessary, and this process is continued until a paper pattern is evolved which will enable the finished article to be formed with the minimum of trimming. This process would only be necessary in the case of a very irregular shape such as a scuttle dash, where the shaping is done partly by bending and partly by stretching the metal. For a simple shape, such as a dome, where the formation is done almost entirely by stretching, the initial sheet should be cut to the same shape as the final perimeter, but with a small margin.

The blank is placed on the sand bag or hollow block, and with a round-nosed wooden mallet it is given a series of light blows round the outside edge. Having gone completely round the circumference, a further series of blows is given, slightly more towards the centre and again completely round in a circle. This process is continued, the hammer blows being directed in a series of concentric circles until the centre is reached. Puckers may then be removed by radial blows, and the work is then tested out for dimensions against a template.

It may then be necessary to go over the whole surface again, always working from the edge towards the centre, and taking out puckers as they occur. The aim is to stretch the

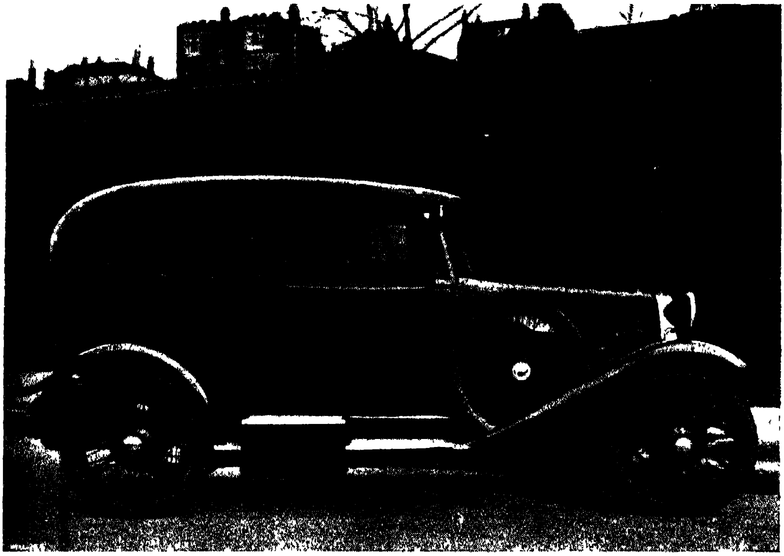


FIG. 51. Car with beaten aluminium body and duralumin supports and wings, made by Short Bros. (Rochester and Bedford), Ltd.

FIG. 52.—Aeroplane fairings hammered in aluminium

[To face page 167.

metal very gradually and uniformly, for if any one part is stretched too much, it is a difficult matter to rectify it afterwards.

Finally, when the true shape and size are obtained, the panel is turned over and transferred for planishing on to a convex head of iron. Planishing consists of hammering with a flat steel hammer over the whole surface in such a way as to remove all irregularities. The planishing is best done with a large number of light blows, and for this reason a power-operated hammer giving blows at a rapid rate is recommended. Each hammer blow produces a flat spot, and the blows should be so directed that the spots merge imperceptibly into one another over the whole surface. The hammer face and the convex anvil head must be perfectly smooth and clean or it will be impossible to avoid marking the sheet. It is, of course, essential that the hammer should strike the metal squarely or it will form a "crescent" difficult to get out.

The planishing should leave the metal with a dead smooth surface which shows no hammer marks, and is fit for polishing without further treatment. When this ideal is not attained small hammer marks can be removed by smoothing off with emery cloth glued to a piece of wood and used like a file.

Two widely different applications of the metal beating process are shown in Figs. 51 and 52, and strikingly indicate the variety of work possible by the process. In the first is shown an aluminium motor-car body made up of beaten panels which are afterwards welded together to form practically a one-piece body of very pleasing design. In Fig. 52 is shown a number of aeroplane fairings also produced by beating. These articles are required in small numbers, but are of so irregular a shape that a large number of operations would be necessary to produce them in a press, and the cost of the dies would be very excessive. These articles were, therefore, produced by beating on an iron former of the internal shape of the article. A cylindrical cup was first formed by drawing in a press, and this was placed over the former and beaten down to shape by hand

hammering. It will be obvious that each half of the fairing must be very accurate in shape and size or the hinged joint will not close properly, but the above method was found very effective in this respect, and the results, as will be seen, are excellent.

Aluminium alloy sheet has sometimes to be dealt with in the sheet-metal shop, and Fig 53 shows the hull of a flying boat formed of shaped duralumin sheets. Aluminium alloy sheets are more difficult to work than pure aluminium, and require more frequent annealing, but nevertheless they are simpler to deal with than steel, especially when the articles are large, in which case the light weight greatly facilitates handling.

FIG. 53.—Shaped aircraft hull in beaten duralumin by Short Bros. (Rochester and Bedford), Ltd.

[To face page 168.

CHAPTER VIII

WORKSHOP PRACTICE.

The production of bright clean-cut surfaces, and accurate machining to fine limits, are essential in the manufacture of automobile pistons, and for a host of other parts for which aluminium is largely used, and it is possible to obtain the same perfection in surface and dimensions with aluminium as with any other metal. It is true that owing to its softness pure aluminium is apt to drag, but good results are, nevertheless, obtainable if careful consideration is given to the form of tool, the choice of lubricant, and the speed of working. Most usually parts which are to be machined are not made in pure aluminium, but are cast in one or other of the well-known aluminium alloys, and these are, in general, more easily dealt with. From the machining point of view the zinc alloys are excellent, the 2L5 alloy (13 per cent. zinc, $2\frac{1}{2}$ per cent. copper), for example, being somewhat similar to a soft brass in its behaviour. The L8 alloy (12 per cent. copper) is also very good, but with the softer alloys, such as the silicon alloys, more care is required to keep the tools keen, and to ensure clearances adequate to prevent clogging of the chips.

All aluminium alloys permit an extremely rapid rate of machining, so that the machining costs, often an important item, are small in comparison with those for cast iron. Indeed, it is sometimes found that the economy on machining is sufficient, combined with the reduction in weight, to justify the substitution of aluminium for cast iron, in spite of the wide difference in cost of the metals as compared on a weight basis.

Turning.

In the literature upon the subject of turning aluminium the reader will find a bewildering variation in the form of tool recommended by different writers, and a probable explanation lies in the greatly different properties of the several alloys dealt with, and the different degrees of temper, heat treatment and physical condition in which aluminium is used in engineering practice. This does not mean that every different aluminium alloy needs a different form of tool, for success or failure does not turn upon an accurate adjustment of clearance angles, radii, and dimensions, and with any one alloy good results would be obtained with a wide range of tool design. Variation would, however, be desirable where widely different forms of aluminium are dealt with, and the tool best for pure aluminium, for example, would not necessarily be best for the harder L8 alloy.

One point applies to tools for working aluminium in all its forms, namely, the necessity for finishing every tool with extremely keen edges. Tools for brass are usually finished on a grindstone with an edge which is comparatively rough, but it is essential for the attainment of a perfect surface with aluminium that the tool should be finished on a smooth oilstone so as to remove all grindstone marks. Not only must the cutting edge itself be keen, but the top surface of the tool over which the chips will pass must also be smooth, so as to provide the minimum amount of friction. This will be helped by arranging that the last strokes during the preliminary grinding of the tool shall be done along the direction that the chips will take. If the grinding is done across the tool, minute scratches, not removed by the oilstone, will tend to retard the smooth passage of the chips, and this will re-act on the nature of the cut. If the minute furrows are in the direction of the chips they will offer less resistance.

As regards the shape of the tool, it will be found that with certain of the harder aluminium alloys the same cutting angles and clearances as normally used for brass will give satisfactory

results. In general, however, the cutting angle should be rather more acute and the side rake somewhat greater. With the softer alloys these modifications should be accentuated, until, when machining pure aluminium or the very soft silicon alloys, the tool angles approach more closely those used for turning hard wood. For these soft materials the cutting angle, i e. the angle between the cutting face of the tool and the tangent to the work (angle α in Fig. 54) may be 45° or less. The round-nosed tool illustrated in the figure is effective either for roughing or for finishing, and the same tool may be used provided that, before commencing the finishing cut, the edge is brought back to its original keenness on the oilstone.

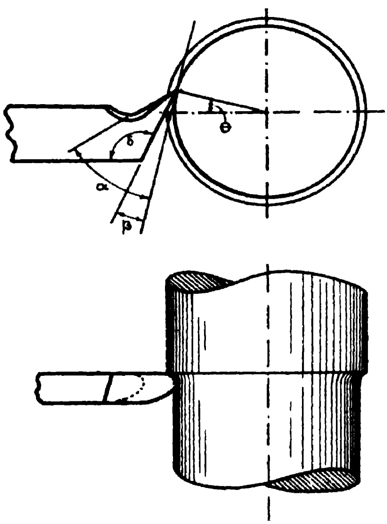


FIG. 54 – Lathe tool angles for use with aluminium alloys

The tool should be set well above the centre line as indicated, as this tends to counteract the strong tendency for the tool to dig into the work if there is the least looseness. An objection to this practice is that, as the diameter of the bar is reduced and the tool is fed forward, the clearance angle β becomes less until at a certain point it disappears entirely, and the front-face of the tool is tangential to the work. This can be overcome by re-setting the tool from time to time, but this is inconvenient, and would not be necessary if the clearance angle β and the offset angle θ are properly arranged. It will be found that if θ is made about 15° and the angle β about 10°, then the diameter of the work can be reduced by about 75 per cent. before the clearance angle and cutting angle become too far reduced for efficient action. When only a small amount of

stock is to be removed the angle θ can, with advantage, be still further increased, but it is, of course, necessary that the tool be ground in accordance with the height above centre to which it is to be set. As a matter of interest it may be stated that the angle δ is geometrically equal to 90° plus the value of $\beta + \theta$, and this relation enables the tool angles to be fixed in accordance with the intended method of setting.

With a tool having the angles mentioned above and a side rake of about 15°, the metal should be removed in the form of a long ribbon which clears the work widely. It is desirable that the chips should not curl back and touch the work, or they may scratch the surface.

The permissible depth of cut when roughing will depend almost entirely upon the means for holding the work. In view of the softness of some of the forms of the metal, the prevention of distortion under the heavy stresses arising from a deep cut is by no means simple. Moreover, if the work is long and thin a small whipping is liable to cause the tool to dig, and it is desirable to use roller steadies both for roughing and finishing.

Given sufficient firmness of grip, a cut of as much as $\frac{1}{4}$-inch to 5/32-inch at a speed of 500 to 700 r.p.m. is not unusual, provided that a suitable lubricant is used to prevent overheating. In most cases rough turning is done dry, in which case a lighter cut must be made.

For finish turning, a high speed with a very light cut and a slow feed is necessary. A speed of 600 to 800 feet per min. is possible with ordinary carbon steel tools, while for high-speed tool steel even higher speeds are permissible without causing a rapid loss of keenness. In general, the higher the speed the better the finish, though this is not invariably the case, and the most satisfactory speed for any particular material is best determined by trial.

A lubricant is essential for the production of a mirror-bright finish, and for pure aluminium and the softer alloys paraffin oil (kerosine) can strongly be recommended. With some of the

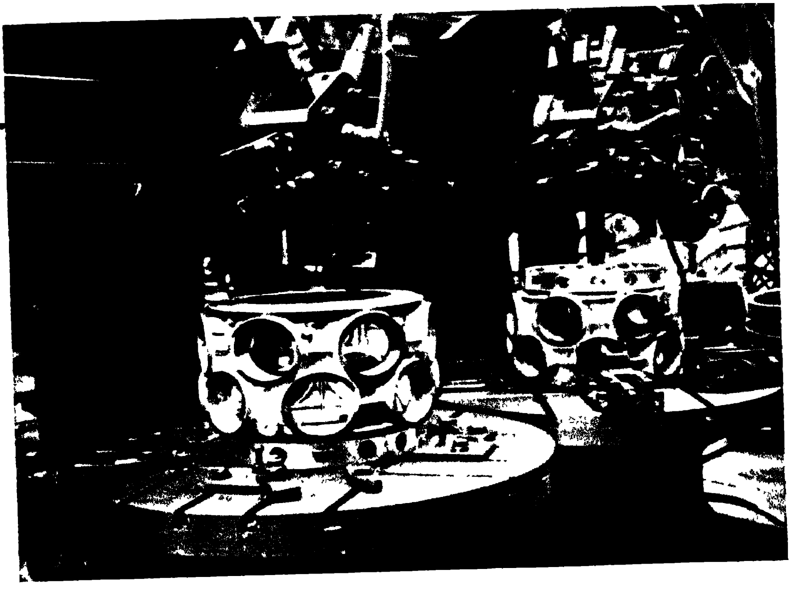


FIG. 55.—Boring and facing operations on the "Jaguar" engine crankcase (Photo by *Machinery*.)

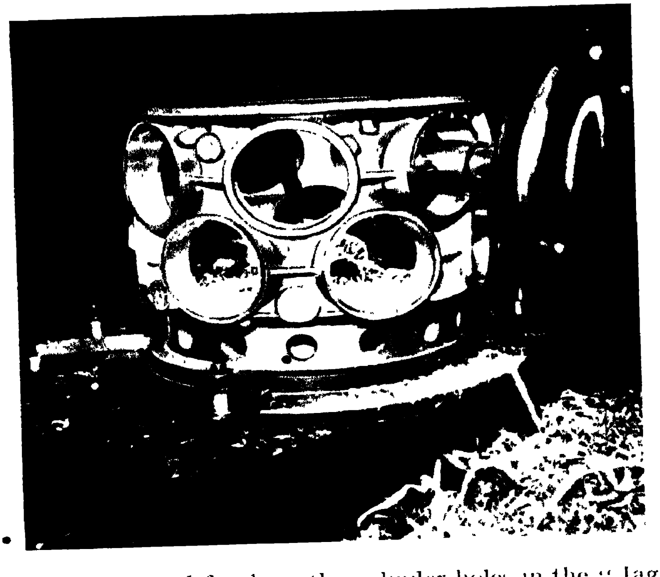


FIG. 56.—Boring and finishing the cylinder holes in the "Jaguar" engine crankcase (Photo by *Machinery*.)

[To face page 172.

harder alloys a mixture of paraffin oil and lard oil, or refined rape oil, in equal proportions gives better results. The lubricant should be applied in a copious stream by means of a pump, and should be played on to the tool in such a direction that it will help to carry away the chips.

For boring tools the angles should be much the same as those described for outside turning, though modifications will be necessary because the tool is then set below centre instead of above centre. The cutting angle and clearance, therefore, increase as the work proceeds, so that these angles may be slightly more acute to commence with.

Screw Cutting.

It is in screw cutting that the machining qualities of a metal are most severely tested, but with the B.E.S.A. casting alloys of aluminium the cutting of screw threads does not present any serious difficulties. In the case of pure aluminium, on the other hand, the cutting of fine screw threads is not to be recommended, partly because of the difficulty of cutting the threads, but principally because, in subsequent use, fine threads are apt to bind and over-ride. Screwed couplings for tubes and rods in pure aluminium are often employed, and are quite successful if a fairly coarse thread is employed. A suitable thread is the standard Whitworth thread or alternatively the British Standard Pipe Thread.

In cutting screw threads in soft aluminium the work should be done in a lathe wherever possible. Dies are apt to tear the thread unless carefully handled, but where it is essential, dies can be used if kept well lubricated with paraffin, and if the initial diameter of the rod is made a little smaller than the diameter required for the finished screw. This latter precaution is necessary owing to the fact that, coincident with the cutting, there is also a squeezing effect which results in the thread being pressed up between the teeth of the die. It is this action which, when not guarded against, is the cause of the majority of failures.

Perfect screw threads can be cut in a lathe, first with a single point tool, followed by a final finishing with a hand chaser. Thorough lubrication during the process has an extraordinary effect in facilitating the work, and paraffin appears to be the most satisfactory lubricant. Turpentine is good, but is not recommended because it leaves a resinous deposit which is liable to cause binding during subsequent use.

In the tapping of holes bees-wax or tallow is sometimes rubbed into the tap as a lubricant, but a good flow of paraffin is preferable. It is very necessary that the hole be drilled to such a diameter that the raising of the thread by pressure in addition to the actual cutting is allowed for. The drills should therefore be somewhat larger than for other metals, and the best size should be found by experiment with the particular aluminium alloy dealt with.

Ordinary taps are quite satisfactory with aluminium if used with care, but taps are obtainable designed with more acute cutting angles specially for aluminium. These give better results, particularly if the flutes are arranged spirally as in a twist drill, as this gives a certain amount of side rake to the cutting edge. Excellent taps for aluminium can, in fact, be made from old twist drills, the drill being first softened, the thread cut, the shank turned down and the whole finally rehardened

In the case of pure aluminium the pressing effect is very marked during tapping, so much so, in fact, that for very small sizes (e.g. 4 B.A. screws and under) effective internal screw threads can be formed by screwing a steel screw into an untapped hole of suitable size. The assembly of light aluminium parts may be facilitated by taking advantage of this, all tapping operations being omitted, and the requisite screw threads being cut automatically by the screws themselves. Such screws will hold quite firmly, provided that they are not often undone and screwed up again. It is not good practice to use small screws, even with aluminium alloys, if they are to be often removed and replaced, and in such circumstances a stud with a nut should be used in preference.

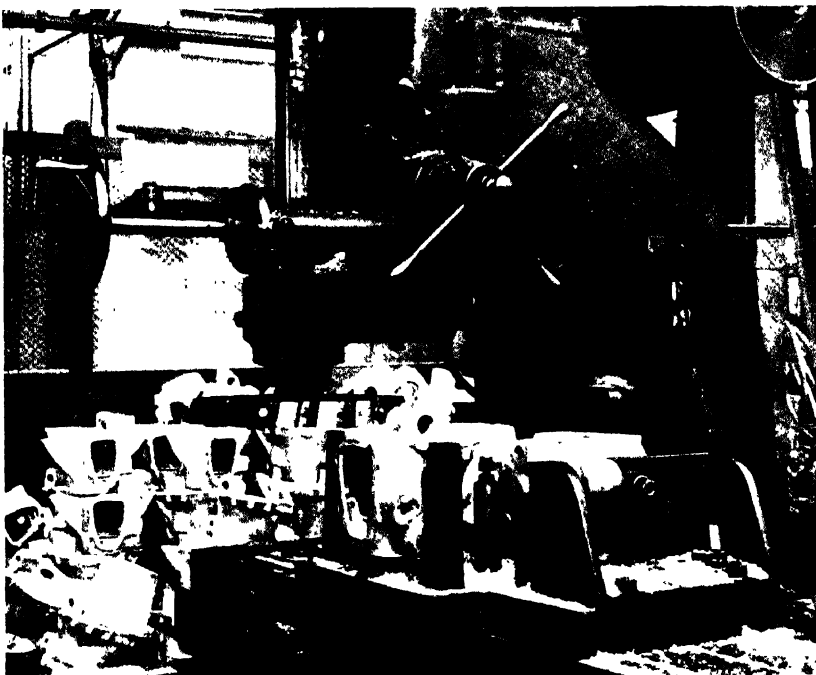


FIG. 57.—Milling aluminium gear boxes at the Clement Talbot works.
(Photo. by the *Automobile Engineer.*)

[*To face page* 175.

For repetition work in aluminium an extremely satisfactory method of screw forming is "thread rolling." In this process the thread is formed by hardened rolls having threads cut on them, which are pressed into the aluminium and raise a corresponding thread by squeezing the metal up. The process is applied very largely for the manufacture of small brass screws, but in the case of aluminium it can be applied for screws up to 2 inches or more in diameter.

Milling.

For the majority of the purposes for which aluminium castings are used the process of milling is the most important machining operation, and it is in this operation also that the machining qualities of aluminium show to the greatest advantage in comparison with iron. Dead flat surfaces of excellent finish are obtainable in a fraction of the time required to obtain equal results with iron, and, moreover, the cutters have a much longer period of useful life. No special precautions have to be taken with aluminium, and the ordinary types of cutter are quite satisfactory, though it may be desirable to grind with a greater clearance and to use tools in which the teeth are set wide apart. This latter point is important because the chips are apt to clog the teeth, and if this occurs a perfect finish is impossible. From this point of view the best form of cutter is that consisting of a cast-iron head with cutters inset, as can be seen in Fig. 57. An interesting feature in this instance is the fact that three cutters only are employed, since it is found that with the large diameter and high speed employed, these give better results than a large number of blades. A further point is that the spindle head is set at a slight angle so that the trailing edge of the cutter takes a skim cut over the part previously roughed by the leading edge. It will be seen, also, that three gear boxes are being milled together, each being arranged in a different position in the fixture, so that in one pass three different milling operations are performed.

In Fig. 57 the work is being done dry, and, in general,

a lubricant is not necessary unless a bright finish is required. In some cases, however, where a tendency for clogging is observed, a stream of soapy water directed at a convenient angle towards the cutting edge will assist to clear the chips away rapidly. For a mirror finish copious use of paraffin is recommended.

Drilling.

Drilling is usually carried out with the standard type of twist drill, and though flat drills are often recommended, these do not appear to show any marked superiority. It is sometimes recommended also that for aluminium drilling a sharper angle at the point is desirable, but it is quite definite that excellent results are obtainable with the standard angle of 118°, and there appears to be little justification for departing from this normal form. With a sharper angle the wedging action of the drill is increased, and in the writer's experience this does not impart any improvement to the work. Indeed, it would seem that if any departure from the standard angle is made, it would be preferable, with soft metals, to increase the angle rather than to decrease it.

The grinding of the drills for aluminium should be so carried out that clearances are large and cutting angles keen. In one form of drill designed specially for aluminium, a particular feature is the small pitch of the flutes of the drill in comparison with the normal standard, the angle which the grooves make with the axis being about 32° instead of the more normal 26°. This means in effect that the cutting angle corresponding to angle α in Fig. 54 will be more acute than in the ordinary type of drill, and the writer has found that these drills do show a marked superiority for these soft metals.

Drills should be run at a high speed of, say, 250 to 300 feet per minute at the periphery, which corresponds to about 1000 r.p.m. for a 1-inch drill. The feed should be moderate, say ·005 inch per revolution for a 1-inch drill and ·003 inch for a ½-inch drill. Lubrication is desirable and paraffin is recommended.

Grinding.

Both rough grinding, such as the removal of the fins from castings, and precision grinding, as is used in finishing a piston to an exceedingly fine tolerance, are widely practised in aluminium. Some care must be devoted to the type and quality of the wheels, because there is an almost infinite variety of classes, and all are of different properties. The abrasive material itself varies widely, and may be a natural product such as emery or an artificial material such as carborundum (carbon silicide) or alundum (aluminium oxide); the binding material may be shellac, rubber, or a vitrified silicate; and the size of the particles may vary from 10-mesh to 250-mesh. In view of these wide variations in the different types of wheel available, and the practical impossibility of devising a reliable standard of "hardness," it is desirable that in selecting a wheel for aluminium grinding the makers should be consulted. The following brief notes on the methods of grading adopted by manufacturers will, however, be of interest.

The hardness or "grade" of a grinding wheel refers to the tenacity with which the binding material holds the individual particles, and is an indication of its wearing ability rather than of the hardness of the individual particles. This wheel hardness is usually indicated by a letter of the alphabet, grade A being the softest and grade Z the hardest wheel. Usually the harder the work the softer the grinding wheel required, because when grinding a hard material the individual particles of the abrasive are blunted quickly, and the binding material should be soft so as to release the grains as soon as they become dull. With aluminium, however, this law does not operate, and a soft or medium-soft wheel is usually employed owing to the tendency of particles of metal to clog around the cutting grains.

The grain size of a wheel is indicated by a number following the alphabetical index of hardness, the number corresponding to the holes per linear inch of the mesh through which all the particles will pass. Thus, for example, a P24 wheel, which is

often used for aluminium grinding, is a wheel of the P grade of hardness made up with grains passing through a 24-mesh.

The "elastic" type of wheel is made by a special process with shellac as the binding medium. Such wheels are usually very thin, and their hardness is often indicated by a number preceding the letter E, the softest being No. ½E, the hardest No. 6½E.

The grain size for aluminium should be medium fine, and a 20-mesh grain is suitable for roughing, while for fine finishing the grain size may be as small as 60-mesh.

The speed of the wheel should be high, the usual peripheral speed being from 5500 to 6500 feet per minute for vitreous wheels, and as much as 10,000 feet per minute for elastic wheels. The speed influences to some extent the effective hardness of the wheel, so that a wheel which is too hard at its normal speed may become satisfactory at a lower speed, and vice versa Thus with aluminium it is found that a rapid clogging of the wheel can often be remedied by running at a lower speed.

With coarse wheels, used for rough grinding, clogging can be prevented by loading the wheel with paraffin wax from time to time. A piece of wax is held against the wheel for a second or two and the open pores between the grains become filled with the wax. This does not impair the cutting ability of the grains, but merely prevents the adhesion of aluminium particles, and at the same time provides a certain amount of lubrication.

In precision grinding the work can be finished if necessary to a tolerance of one-ten-thousandth of an inch, although normally a much wider tolerance ($\pm$ ·001 inch) is all that is necessary. With exceptionally fine tolerances particular care must be taken to ensure that the work is cooled to the room temperature before measuring. The coefficient of expansion of aluminium is twice as much as that of steel, and on a 4-inch diameter piston, for example, a rise of temperature of 1° C. is enough to expand the diameter by ·0001 inch. A 10° rise of temperature is easily produced during the working, and it

is, therefore, essential that the work shall be cooled to a uniform temperature before measurements are taken. In certain special work it is necessary to state the temperature at which the dimensions are to be measured, since a 10° C. change in the temperature of the workshop is quite possible on consecutive days.

Filing.

Though the metal can rapidly be removed in filing aluminium, the production of a scratchless finished surface is difficult, owing to the rapidity with which the file becomes clogged. For this reason the files used should preferably be of the single-cut type in which the teeth are formed by straight cuts approximately at 45° to the axis of the file, or alternatively by cuts in the form of circular arcs. The more usual double-cut files, where the teeth are formed by two sets of cuts crossing one another, are much more quickly clogged. Single-cut files are obtainable in all grades from rough to smooth, and this provides a sufficient range of coarseness for all normal work. Double-cut files are obtainable in an exceptionally fine grade known as dead smooth, but even such files can be used on aluminium, where an extremely high finish is to be obtained, if they are kept wet with paraffin. The use of a lubricant is of astonishing efficiency in preventing files from clogging.

Clogged files can readily be cleared by an ordinary wire brush, but a still quicker method is to plunge them for a few moments in a strong solution of caustic soda. This loosens the chips which can then be easily wiped off. It is important, after this treatment, that the files should be washed in running water, and carefully dried in sawdust, or they are liable to rust. Sand-blasting is another good method of cleaning files.

Sawing.

For cutting off the risers and runners of aluminium castings an excellent machine is a band saw of the type used in woodworking, and where much sawing of aluminium is to be done

such a machine can economically replace the ordinary reciprocating saw for general work. The saw should have coarse teeth and be run at a high speed (600 feet per minute). These machines are not usually arranged for working with a lubricant, and dry cutting is quite satisfactory unless a fine finish is required.

Hand cutting is done with an ordinary hack saw, preferably with a coarse-toothed blade. Thin sheet metal can be cut with a woodworker's tenon saw, and a sharp clean edge can afterwards be obtained by planing with a woodworker's jack plane.

Hot Forging.

The process of hot forging offers an alternative to casting which is valuable where the improved strength and ductility of the part as so formed will justify the additional cost. The process has been adopted for the manufacture of connecting rods, switchgear components, and similar parts where the maximum possible strength combined with the smallest possible weight is of considerable importance, and hence developments in the hot forging process have proceeded principally with Y-alloy, duralumin, and other special alloys which are heat-treated after forging. The process is applicable to the majority of the ordinary casting alloys as well, and alloys containing 10 per cent. to 13 per cent. of zinc with 1 per cent. to 2 per cent. of copper provide ample strength for many purposes without necessitating any special form of heat treatment. Good results are also obtainable with the low copper alloys (up to 4 per cent.) with or without an addition of about 1 per cent. of manganese. These alloys are capable of being forged over a much wider range of temperature than the alloys of the duralumin class, and the process is correspondingly easier.

The temperature of working is, perhaps, the most powerful factor influencing the success or failure of the process, and with duralumin or Y-alloy it is essential to employ an accurate means of temperature measurement and control. Forging at too high a temperature will cause the metal to crumble to

FIG. 58.—Typical forms of die pressings. [*To face page* 181.

powder; forging at too low a temperature will so harden the metal that it cracks under the deformation. For duralumin and Y-alloy the temperature range for forging lies between 470° C. and 490° C.; for alloys of the copper or manganese-copper class the range is from 350° to 500° C.; and for alloys of the zinc-copper class forging should commence at about 450° C. and can continue down to 350° C. without excessive hardening.

The heating is done in a closed muffle furnace which should be run at about 25° to 30° above the upper limit of the forging temperature. A higher muffle temperature would involve a more rapid attainment of the correct forging temperature in the metal, but the danger of over-heating is sufficiently serious to make this inadvisable. The time taken for the heating depends on the bulk of the metal, but roughly it may be taken that, at the furnace temperatures above recommended, 1-inch diameter stock will require about twenty minutes, and 2-inch diameter stock about an hour. A certain amount of experimenting will be necessary to determine just exactly how long the stock should be allowed to remain in the furnace to attain the best temperature. When the right temperature has been attained there should be no undue delay in transferring the heated metal from the furnace to the presses.

The actual process employed in forging is the same as that used with steel, and aluminium may be forged by die pressing, drop forging, or even by the ordinary blacksmith's hammer. In die pressing, which is particularly adapted for the production of such articles as the hub cap shown in Fig. 58, the blank, previously cut from a rod and heated to the required temperature, is placed in the lower half of a die the shape of which corresponds to the outside of the finished article. A punch, shaped to the required form of the inside of the article, descends in such a way as to squeeze the hot metal into the space between the punch and die. The blank is entirely enclosed within the lower die, so that during the plastic formation of the article the dies are subjected to very considerable fluid pressure, and

must be designed accordingly. When turned out, the article is remarkably true to size, with sharply-defined corners, smooth surfaces, and without fins. The pressings have, in fact, the majority of the advantages of pressure die castings with the added advantage that the metal is compact in structure, and entirely free from porosity, blow-holes, or other foundry defects. The process is, however, limited to comparatively simple shapes, and it is impossible to employ cores or other loose pieces in the dies for the production of undercut holes or re-entrant shapes. Moreover, the process is practically confined to the production of comparatively small work, of the order of not more than half a pound each, owing to the heavy pressure required.

The most suitable type of press appears to be the power-operated screw press, in which the upper die-holder is raised or lowered by a screw, driven by a heavy flywheel attached to its upper end. Crank presses are also used, but these do not give the same uniformity of pressure throughout the entire stroke as the screw press. Drop hammers are occasionally used, but these also are not so satisfactory in that the blow is sudden and violent, and thus does not conduce to the ready filling of all interstices of the mould in one stroke.

In the second form of forging, known as the drop forging, the filling of the dies is attained not by a continuous squeeze as in die pressing, but by a hammer blow or a series of hammer blows. The drop forging process is applicable to a much wider range of size and shape, but the drop stamps do not turn out the work completely finished, and trimming is necessary to remove the fin invariably left.

In many cases the stampings may be made direct from a long straight bar, one end of which is held by a pair of tongs while the other is laid on the lower half of the die. When the forging is complete it is still attached to the rest of the bar by a thin fin, but this is readily broken and the shaping of the next part proceeded with. This process is continued throughout the whole length of the bar, or until reheating becomes necessary.

With more complicated forms of article this process is not possible, and a preliminary shaping may be necessary, either in a special pair of dies, or, sometimes, between the pallets of a blacksmith's hammer. In the latter method of forging it is desirable that the shaping shall be done with the metal "in the square"; that is, in getting down from a large section to a small one, even though the final section is required to be round, the section of the bar should be maintained square until the final stage. When the side of the square is about equal to the required diameter, the bar should be turned through 45° and then through 90°, thus obtaining an octagonal section which can be reduced to a true round in the ordinary swages. Unless this practice is followed there is a tendency for piping, especially with duralumin and similar alloys which harden rapidly.

Light rapid blows are best with all aluminium alloys owing to their low strength at the forging temperatures. A heavy blow in forming a neck, for example, may cause the metal to shear off. This does not apply when forging in dies, of course, and when the metal is supported in dies the heaviest blow which the machine is capable of giving is required to cause the metal to fill all the interstices properly.

In the final shaping it is desirable, where possible, to avoid sharp corners to depressions, because the metal does not flow so readily as steel. When sharp corners are essential it is often necessary to use two sets of dies, with a reheat between each, and so to obtain the final shape by stages. When heavy masses are to be formed in conjunction with thin sections this is also desirable, because the thin section, if obtained in one blow, will be cooled more rapidly than the heavy section, and may, therefore, be reduced below the safe working temperature while the heavy section is still within the forgeable range.

Apart from these differences, the dies for forging aluminium are the same as those for forging steel, and the same allowance for shrinkage is made, for though the coefficient of contraction is greater for aluminium than for steel, the temperature range is very much smaller.

An advantage of aluminium forging is that the metal does not scale as does steel, so that it is unnecessary to use the air blast common with steel forging for cleaning the dies, and no scaling operation is required however many reheats may be necessary. Also, the dies themselves need not be lubricated, though this necessitates that the die surfaces should be finished particularly bright to ensure a smooth surface on the work. When lubrication is employed tallow has been used with success.

The dies are, of course, heated before commencing operations, and it is particularly necessary to ensure that they have attained a reasonable temperature when such metals as duralumin are being dealt with, owing to the small range of temperature over which these are forgeable. The ordinary method of heating the dies is to place between them, for an hour or two before commencing work, a block of heated iron.

The raw material used for forging is usually supplied in the form of rolled or extruded bar. Forgings can be made from cast metal, but the rolled metal is in a better condition for plastic formation, and is almost invariably adopted.

Bushing.

The ordinary aluminium alloys do not wear well under rubbing or percussive action, and hence it is often necessary to insert bronze or steel bushes to take wear. In certain cases these may be fixed during the casting, the insert being placed in the mould and the aluminium cast round it, as shown in Fig. 23. The surface of the bush is grooved so that the molten aluminium can enter and obtain a firm grip. This process is undoubtedly the most satisfactory method of fixing in these bushes, but in many cases the shape and size of the work will preclude the practice owing to the danger of cracking, and the bushes are then fixed by shrinkage, or screwing, or both. When shrinking a bush into place the usual allowance is from 0·005 inch to 0·001 inch for diameters up to half an inch, and from 0·0015 inch to 0·002 inch for diameters from half an inch to 1 inch. For example, for a 1-inch diameter bush

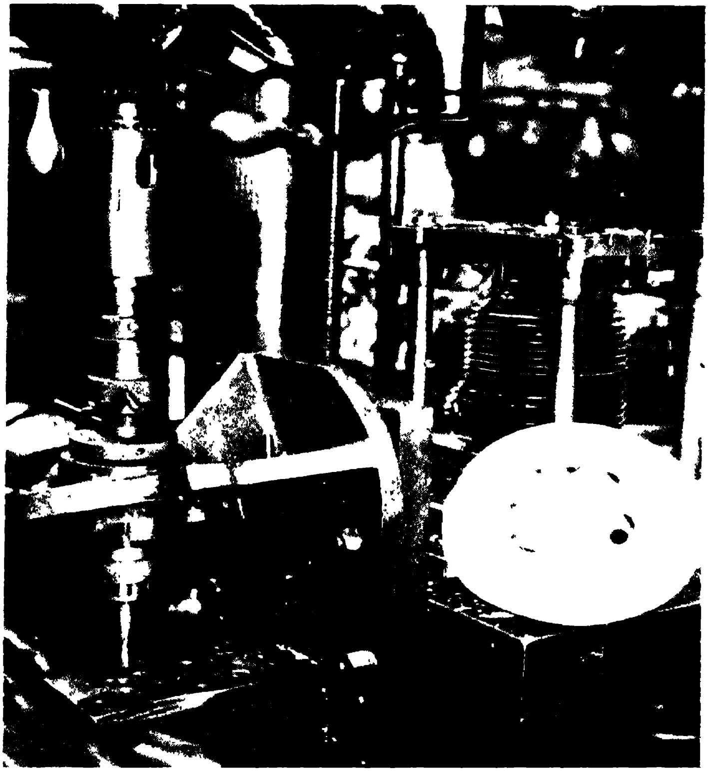


FIG. 59.—Arrangement for expanding the valve seatings into the aluminium cylinder head of the "Jaguar" engine (Photo by *Machinery*.)

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the hole in the aluminium would be finished to 1·0000 inch (tolerance = + 0·0005 inch) and the bush would be finished to 1·0020 inch (tolerance = – 0·0005 inch). With these tolerances the maximum difference between the hole and bush diameter is 0·002 inch and the minimum difference 0·001 inch.

When the temperature of the aluminium is raised, by a gas blow-pipe or other means, to about 100° C., the bush will slip into the hole easily, and will be firmly held when the aluminium is allowed to cool again. In view of the comparatively small temperature rise necessary to loosen the bush, it will be evident that shrinkage will not be sufficient for the valve seat bushes in an automobile engine, or for any application where considerable increases in temperature are likely to be encountered. Valve seat bushes are therefore screwed in and often are expanded after screwing home. The equipment used for the latter purpose in the case of the "Jaguar" engine (Messrs. Armstrong-Siddeley Motors Limited) is shown in Fig. 59. In this engine the valves are carried in the aluminium cylinder head, which is shown in the illustration, and after the bushes have been screwed home the cylinder head is clamped to the under-side of an inclined bracket fastened to the bed-plate of a radial drilling machine. The spindle of the drilling machine, carrying an ordinary tube expander, passes through the valve hole, and when the tool is rotated the rollers at the lower end of the expander are forced outwards against the bushing. The working faces of the bushes are afterwards turned to ensure truth with the valve guide holes.

Aluminium Jigs.

A useful application of aluminium in the machine shop, which is not sufficiently appreciated, is for the manufacture of jigs used for locating holes in repetition work in the drill press, etc. Such jigs, when made in iron, are often heavy and cumbersome, and quite usually may be several times heavier than the work itself, so that the advantage of substituting aluminium will be obvious both as regards lightening the work of

the operator and also as regards lessening the stresses thrown upon the machine.

Aluminium jigs have sometimes been used when the work itself is of aluminium, based on the underlying idea that any changes in dimensions of the work due to temperature changes will automatically be rectified by a corresponding change in the jig ; but it is doubtful whether any such changes are worth taking into account, since the temperature variation in a modern workshop throughout the whole year is not likely to be more than 15° C. as a maximum, and with this change in temperature the alteration in dimensions between two holes one foot apart in an aluminium article will not exceed 0·004 inch. In iron the corresponding variation would be 0·002 inch, and it will be apparent that the difference in expansion between an iron article and an aluminium jig will be too small to have any influence on the choice of material for the jig.

In the design of an aluminium jig it will be evident, from what has already been said, that the drill holes must be bushed to prevent wear, and also that it may be necessary to incorporate steel locating stops, clamps, etc.

Some interesting features of this kind are to be seen in the jig shown in Fig. 60, used for operations on the instrument case also illustrated. In this, the work is placed on the faced plugs and is centred by the two pairs of equalising jaws L and M. These are operated by rods O, N, screwed with right- and left-hand threads which engage with swivelling members PP in such a way that the jaws M, L, are caused to swing in or out on turning the knurled discs at the centres of the rods. The jaws L float at the ends of the lever arms so that they adapt themselves gently to the corners of the work.

When the work is in place the lid is closed down and secured by the two buttons KK, and the work is lightly clamped by thumb-screws in the lid.

It is significant that while these particular jigs were originally described in the *American Machinist* in 1911, they are still (1927) in practical operation.

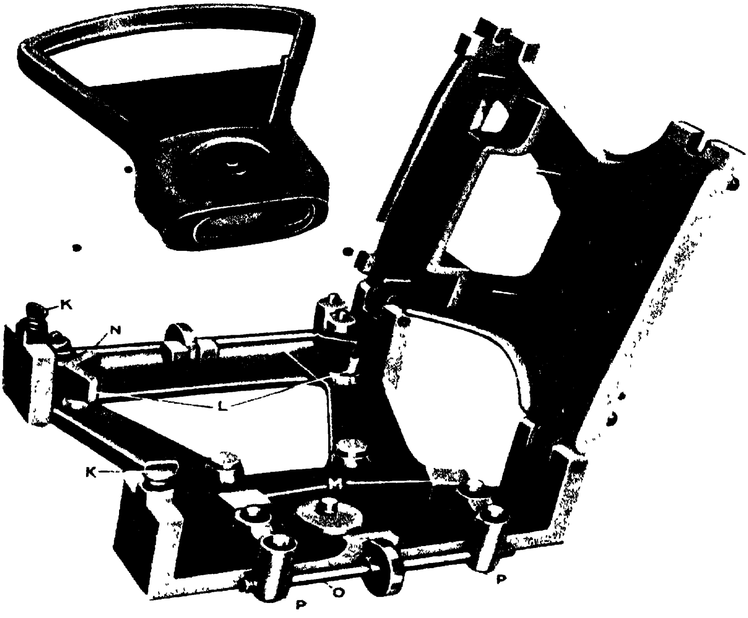

FIG. 60.—Aluminium jig used for drilling operations on the meter case shown.

[To face page 186.

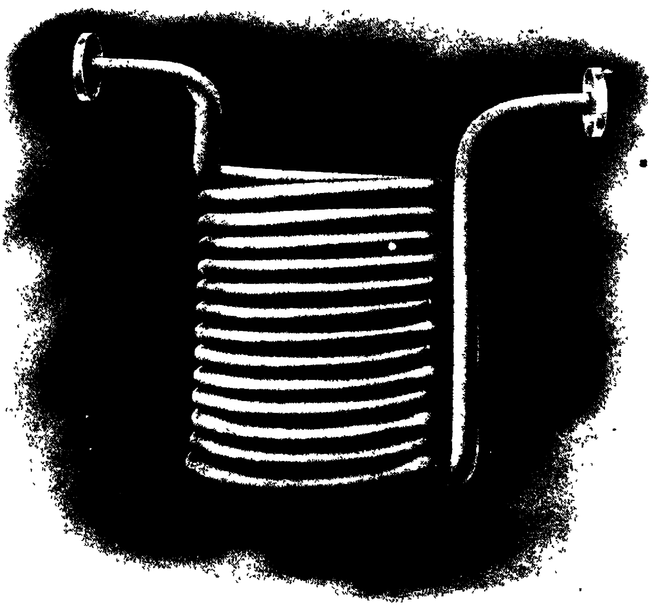

FIG. 61.—Condenser coil of aluminium tubing.

[To face page 187.

Pipe and Rod Bending.

The bending of tubes and rods in aluminium is easily carried out by simple leverage if the metal is given a preliminary warming at the required spot. Tubes should be plugged and filled with sand in the ordinary way, and if a complete spiral is to be made, as in Fig. 61, a good method is to warm the sand before filling it in. This will be sufficient to soften the metal and allow the bending to be done by hand round a suitable mandril.

The angle of bend may be much sharper than for steel, and solid rods may be bent round a radius equal to their own diameter. Tubes are not usually required to be bent to sharp radii, but where necessary it is possible, with tubes of ordinary thickness in relation to their diameter, to bend round a radius of twice the outside diameter.

CHAPTER IX.

FINISHING.

While the value of aluminium for the majority of its applications resides in its special physical properties, it is indisputable that an attractive appearance will materially add to the selling value of an article. Thus the value of aluminium for cooking utensils lies in its excellent heat conductivity, its long life, and general cleanliness, and the housewife who has once tried aluminium will not readily return to iron or enamelled ware; but it is possible that the fascination of the mirror-like polish of a new aluminium saucepan is a more potent factor in inducing sales than the really strong advantages of the metal for kitchen use. The subject of finishing is, therefore, worthy of a very careful study, and though certain finishing processes employed with other metals are not so readily applicable to aluminium, the manufacturer will find a sufficient diversity of different types of finish to satisfy all needs. More particularly is this the case in that different finishes may be applied to different parts of the same object to obtain the benefit of contrast. In the case of a saucepan, for example, an excellent appearance is provided by a polished exterior with a scratch-brushed interior; and in the case of a motor car name-plate by an enamelled background with the high parts polished.

Polishing.

The polishing of aluminium, whether of castings or of sheet metal, is carried out in much the same way as for other metals, although aluminium is so much softer that it must be treated more delicately. When the shape of the article permits,

polishing is done on the ordinary mop, castings being given a preliminary roughing with emery, which should be used with plenty of grease,—tallow for preference. Rough castings may necessitate the use of two wheels, the first with about No. 80 grit emery, followed by a No. 120 grit wheel. Chill castings, on account of their much better surface, can usually be cut down ready for polishing on one wheel alone, using a No. 150 grit abrasive.

The abrasive is applied to the wheel with glue in the ordinary way, and the type of wheel employed depends largely on individual taste. Where repetition work is carried out, much time and cost is saved by the use of compress canvas wheels with faces shaped to fit the work.

The speeds necessary for roughing are not higher than is usual with other metals, a common value being 2000 feet per minute, which, with 12- to 14-inch diameter wheels, corresponds to about 2000 revolutions per minute. For the final buffing the highest speed possible is desirable, using a very soft wheel.

The first stage of buffing is done with a very greasy tripoli compound, of which many varieties are supplied by different makers. Ordinary polishing compounds consist of about 80 per cent. of a ground natural abrasive, such as tripoli, mixed with stearin and a small proportion of lime. Many different grades are supplied according to the grain size of the abrasive particles, and the choice should be determined only after trial of several of the grades available. Aluminium is one of the softest metals with which the polisher is called upon to deal, and, as would be expected, the attainment of the most brilliant polish necessitates the use of the highest possible degree of fineness in the abrasive particles. On the other hand, few manufacturing processes are so perfect that the articles can economically be polished in one buffing with the finest grade of polishing compo ; even drawn or spun metal articles will usually exhibit faint tool marks or surface irregularities, the removal of which with a fine compo could only be done at an

inordinate expense in time, power and material. In such circumstances the polishing might be done in a number of graded operations, first a preliminary buffing with a coarse compo, followed by a high-grade fine compo, and a final dry mopping with lime.

Ordinarily, however, the perfect finish so obtainable would be too costly for commercial work, and sheet-metal articles are usually finished with one buffing process only, followed, of course, by the usual dry lime "colouring." The selection of compo then involves a compromise, for too coarse a material gives a poor finish and too fine a material adds unduly to the cost, both of which factors would have a tendency to restrict sales.

Perhaps one of the most vital features of a good polishing compound is uniformity of grain size, for it will be evident that however finely the bulk of the abrasive material may be ground the presence of a few coarse grains will result in scratches in the final surface. It is in this respect that the cheaper brands of polishing compo differ chiefly from the more expensive, and an examination of two different compos sold for aluminium polishing showed that while in the more expensive brand 98 per cent. of the particles passed through 200-mesh, in the cheaper brand the particles were much more diverse in size and there was an appreciable quantity of dangerously coarse grains.

A screen analysis of the material gave the following results :

Passed	200	I.M.M.,	75·5	per cent.
Retained by	200	,,	16·0	,,
,, ,,	150	,,	4·0	,,
,, ,,	120	,,	3·0	,,
,, ,,	90	,,	0·27	,,
,, ,,	60	,,	0·2	,,

The presence of even a small proportion of grains retained by 90-mesh and larger is sufficient to prevent the attainment of a perfect finish, and it is usually advisable for high-class aluminium polishing to expend a few shillings more per cwt.

on the compo in order to obtain a high-quality material. Makers of polishing compounds do not usually give any guarantee as to grain size, but it is their practice to grade the higher-priced materials carefully, and the rest of the abrasive powder is employed for cheaper blocks which are subject only to rough and ready grading.

Few polishers mix their own polishing compounds, since the commercial products are found to be equally cheap and possibly more reliable.

The wheel should be kept well filled with the compound and raked out from time to time if the face becomes caked and hard, or wheel marks will be left on the work.

After the buffing the articles may be sufficiently greasy to necessitate washing in benzine, though this is rare, and the usual dry mopping with lime or white "diamond" compound will usually be quite sufficient.

The use of polishing compounds with a rouge base is not to be recommended with aluminium, since these are apt to enter into minute surface pores and give the metal a faint reddish tinge.

Tumbling.

Small castings can be prepared for final polishing by tumbling with steel balls in a wood-lined barrel half-filled with water, to which a small quantity of oxalic acid or, alternatively, a neutral soap solution is added. The process is the same as that used for iron or brass castings, except that the barrel is rotated at a comparatively slow speed. A period of two to six hours would be sufficient for the majority of cases, though in special cases much longer times may be necessary. Very rough castings may be given a preliminary treatment with coarse sand in place of the steel balls.

Frosting.

A matt surface on aluminium is produced by dipping the article into a hot caustic soda solution, which attacks the

metal chemically with the evolution of hydrogen. On immersing the article a brisk evolution of gas occurs and the surface will be attacked immediately, but it is desirable to allow the action to continue for at least 30 seconds, in spite of its apparent violence, or the surface may not be evenly acted upon.

On removing the articles from the bath they will usually be found blackened due to the iron impurities present, but this is removed by dipping in a bath of concentrated nitric acid or a mixture of equal parts of nitric and sulphuric acids.

As carried out on a commercial scale, the dipping shop will consist of a series of tanks, as follows :—

(1) Caustic-soda tank, which should preferably be made of cast or wrought iron. Enamelled iron is often used but the enamel is attacked by the alkali. Plain iron tanks if used regularly are quite durable, though if used only occasionally and allowed to become dry they are subject to considerable rusting.

This tank is fitted with a steam heating coil, by which the temperature is maintained at from 150° to 180° F.

(2) Cold-water tank to wash off the alkali prior to dipping in the acid tank. It will be appreciated that if this tank were omitted the acid solution would have a very much shorter life.

(3) Acid tank, preferably made of porcelain or lead-lined wood.

(4) Steam-heated hot-water tank for final rinsing.

(5) Sawdust tank maintained at a reasonable drying temperature by surrounding it with a hot-water bath or, preferably, by fitting it with steam coils.

The articles pass continuously from tank to tank, small articles being dealt with in batches by placing them in trays and large articles passing through individually.

The various tanks should be kept clean, particularly the caustic-soda tank, in which a brownish-white heavy deposit is apt to form. If this is allowed to accumulate it cakes into a solid mass which is only removable by hammer and chisel.

The soda is gradually used up, but it is wasteful to add fresh soda from time to time to the tank, since this usually means that the solution is made too strong for efficient working. It is preferable to arrange some system whereby at the close of every day (or week, depending upon the use) the partly exhausted soda tanks are allowed to stand for about an hour, and the clear upper portions then bailed out into other tanks and used for lighter frosting. The residue is cleaned out, and the tanks replenished with entirely new solution made up to the strength found most suitable for the class of work being done. For very light frosting, little more than a cleaning, 8 ozs. of soda per gallon of water is all that is necessary, but for heavy frosting, or for work which, by reason of its size or shape, can be passed through the baths very quickly, the solution may contain up to 2 lb. per gallon.

The articles must not be touched by hand in passing through the different baths, and they are either carried in wooden trays or, if this is out of the question, they are handled by wooden sticks.

Articles which are to be partly frosted and partly polished are first frosted all over and the polished parts treated afterwards.

Satin Finishing.

A fine finish, which by reason of its different sheen in different light directions, gives a satin effect, is obtained by scratch-brushing on a soft steel wire scratch-brush, which should be about 6 inches diameter and be run at 1200 to 1400 r.p m. The wheel is run dry and a little lime is occasionally applied to the wires to ensure their freedom from grease. Only a very light pressure is necessary, as the finish is produced by the tips of the wires, and heavy pressure, by bending the wires down, causes less effective results. The work should be held steadily against the wheel and all strokes be given in exactly the same direction, for the attainment of the true satin effect depends upon the skill with which all the scratch marks are made parallel to one another.

Special effects are obtainable by arranging for certain parts of the object to be scratch-brushed in one direction while others are scratch-brushed at a different angle, so that the various portions reflect light differently. Good effects are also obtained by rotating the work and holding the scratch-brush stationary. The well-known " sun-ray " finish to the inside of a saucepan is obtained on this principle, using emery cloth, held in the hand, instead of a wire brush.

This same principle is the basis of the process of " curling " on aluminium, in which the whole surface is patterned by a series of circles marked on the metal by means of a leather-ended tool loaded with fine emery, which is rotated in a lathe. The work is polished to start with, and the very fine scratches made by the rotating tool catch the light and reflect it in definite directions. A number of different effects is obtained by arranging the circles to overlap one another in varying types of pattern.

Sand Blasting.

Sand blasting produces a pleasing greyish finish to aluminium, which is often applied to castings in preference to dipping. It is considerably quicker and cheaper than the dipping process and is more easily applied to a casting, which, if large, is by no means readily handled for transference from tank to tank. Moreover, castings which are slightly porous are apt to absorb the caustic soda, and special care is necessary in the washing to ensure its complete removal.

Sand blasting is carried out on any of the usual types of machine, using a comparatively low air-pressure of 5 to 10 lb. per sq. in. The sand used should be of fine grain, e.g. passing at most a 30-mesh sieve. Still finer sands can be used with sheet metal to produce a very delicate matt surface suitable for instrument dials or for plates for printing upon.

Electroplating.

While there is no difficulty in obtaining an electrical deposit of nickel, silver, or other metals upon aluminium, such deposits

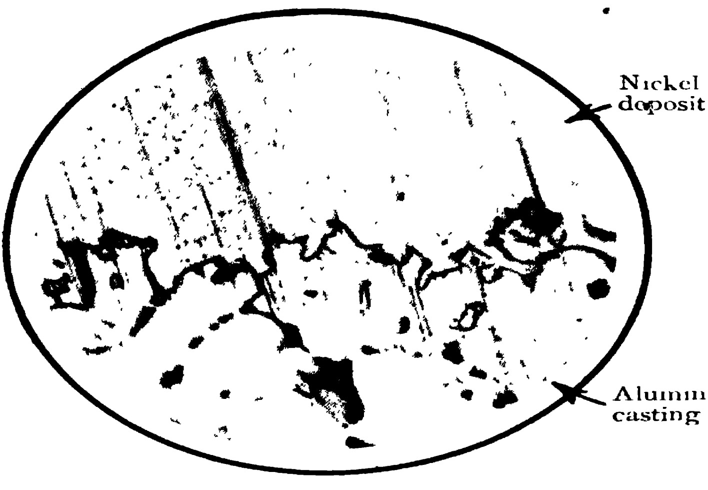

FIG. 62.—Electroplating on aluminium (Section magnified 300 diameters).

[To face page 195.

are apt to strip easily. A contributing cause is the wide difference in the thermal expansion coefficients of aluminium and the deposited metal, and poor adhesion may also be due to the presence of oxide films on the aluminium. Further, even though good adherence may at first be attained, exposure to damp air would be sufficient to set up electrolytic action if the deposited metal should be slightly porous or if its continuity should be broken by a crack, however small. Hydroxide deposits would then form beneath the plating, resulting in blistering, stripping, and an increasingly rapid rate of deterioration.

For these reasons the electroplating of aluminium is not widely practised though much experimental work has been done on the subject. This work seems to point definitely to the fact that the most important influence on the success of the result is the initial preparation of the surface for plating rather than the particular plating solution employed.

The first essential is the removal of all grease, but the usual alkaline cleaning dips are not to be recommended, especially with castings, since the soda may enter the pores of the metal, from which it is difficult to wash it away. The result is that after the object has been plated the small pores develop into seats of corrosion beneath the coating, and blisters will form, which will be found filled with aluminium oxide. An alkaline dip is more satisfactory if followed by an acid dip, but it is desirable to avoid chemical cleaning altogether and to employ *sand blasting* for this purpose when facilities are available.

The next step is to etch the surface of the aluminium to provide a suitable holding surface for the deposit, such, for example, as that shown in the photograph in Fig. 62. This shows a nickel deposit on the surface of an aluminium alloy casting, and it will be seen that the aluminium surface is covered with fine under-cut pits. The deposit is, therefore, mechanically inter-locked with the aluminium base, so that even were molecular contact absent owing to the presence of an oxide film, adherence would, nevertheless, be good. It may

be stated that the particular specimen photographed showed exceptionally good adhesion of the plating, and it was found exceedingly difficult to remove the deposit either by repeated heating and cooling or by mechanical abrasion.

Sand blasting itself is capable of producing a surface satisfactory for taking the deposit without further treatment, but it is likely that much of the success of this simple process depends upon a proper selection both of the sand and of the blast pressure in accordance with the nature of the aluminium being treated.

As regards purely chemical etching agents, it would appear that of all the different materials which have been put forward, the most generally satisfactory is ferrous chloride. Good results are obtained by suspending the aluminium article for a few minutes in a solution of ferrous chloride in dilute hydrochloric acid, and then transferring immediately to the ordinary metal plating bath. In the course of some researches on behalf of the Department of Scientific and Industrial Research at Sheffield University,* however, it was found that still better results are obtainable by electrolytic etching in a bath containing—

Ferrous chloride . . .	200 grams.
Calcium chloride . . .	175 ,,
Water	100 c.c.

The article to be plated is made the anode in this solution for 30 to 60 seconds, with a current of 30 amps per sq. ft. The current is then reversed for 30 to 60 seconds so that a minute deposit of iron occurs. The article is then washed quickly in hot water, dried, again sand blasted, and transferred at once to the plating bath.

An alternative process which was found even more satisfactory is to deposit a thin film of copper by a 30- to 60-second plating in a hot copper cyanide solution, after the initial sand blasting, and, after washing and drying, to sand blast again before transferring to the main plating bath.

* Desch and Vellan, *Trans. Far. Soc.*, 1925.

These particular researches were specially concerned with the electro-deposition of cadmium upon aluminium, this metal being found to provide better protection against corrosive influences than nickel, but good coherent coatings of nickel were found quite readily obtainable after the preparation described, using an ordinary nickelling solution. The solution recommended is that containing nickel sulphate, ammonium chloride, and boric acid, as described by D. J. Macnaughton in the *Journal of the Iron and Steel Institute*, 1924, Vol. I., page 416.

The solution used for cadmium plating is made up as follows: 100 grs. of cadmium sulphate is dissolved in a small quantity of water and ammonia solution added until the precipitate is just re-dissolved. A freshly-made solution of about 3 grs. of peptone is then added to the solution, which is then diluted to 1 litre. The free ammonia should be about 2·5 per cent., and is determined by titration. In the absence of such an excess the deposit is dark in colour. A freshly-made solution must be "aged" before it will give satisfactory results, and this is done by suspending strips of cadmium in the solution as a cathode and passing a current for 24 hours. The solution is then ready for use.

The anodes used are of cast cadmium, large in proportion to the area of the cathode, and the current density is 5 to 7 amps. per sq. ft

After a period of continuous use a regenerative process is applied in which the solution is acidified with sulphuric acid, boiled with powdered charcoal, and allowed to digest in a warm place, after which it is filtered, brought back to the original alkalinity, and mixed with fresh peptone. The bath so regenerated from time to time apparently remains good for an indefinite period.

Blackening.

Copper, brass, silver, and many other metals can very simply be given a dark "bronzed" or "oxidised" finish,

owing to the readiness with which dark-coloured oxides, sulphides, or other compounds of the metal can be produced upon the surface. The common compounds of aluminium are, however, quite colourless, so that the formation of a blackened surface on this metal by chemical means is not so readily effected. A large number of different processes are based on the deposition upon the surface of the aluminium article of a film of some dark-coloured compound of another metal. For example, if the article, after cleaning, is dipped into a solution of cobalt nitrate, and afterwards heated, the nitrate is decomposed with the formation of a black oxide which remains on the surface. Similar results are obtained by using a solution of copper and ammonium chlorides, made by dissolving 60 grams of copper chloride in 300 c.c. of water, and adding ammonia until the precipitate first formed is re-dissolved. On immersing aluminium in such a solution, warmed to about 80° C., a deposit of copper will be formed on the surface. This should be washed, first in hot water and then in a weak acetic acid, to neutralise excess of ammonium salts. On then heating the aluminium to about 500° C. the copper film is converted into an oxide film and the metal becomes covered with a deep black velvety deposit. Unfortunately this deposit is not very strongly adherent, and it is necessary to protect it by a coat of lacquer or it will readily be rubbed off in service.

Better adhesion is provided by the use of the following two solutions, and this method has the advantage that no heating is required:—

1.	Ferrous sulphate	1 oz.
	White arsenic	1 oz.
	Conc. hydrochloric acid	20 ozs.
	Water	20 ozs.
2.	Ammonium molybdate	1 oz.
	Yellow prussiate of potash	1 oz.
	Water	10 ozs.

The first solution is best made by first dissolving the arsenic in the acid, heating as required, then dissolving the sulphate

in the water, and finally adding the two solutions together. The second solution is made by adding the salts directly to the water and heating.

The aluminium articles, after cleaning and light frosting, are immersed in the first solution for a few moments, and will be found to acquire a greyish coating. They are then transferred to the second solution, which is used boiling, and the coating will then be very much darkened and at the same time will become harder and more adherent. The final appearance is not always uniformly black, and faint tinges of green and blue, seen in certain aspects by reflected light, give the appearance of oxidised bronze. The effect is very pleasing for gas and electric light fittings, and for imitation antiques and artistic objects generally.

Another form of black finish is provided by a very simple but effective process which consists in dipping the specimens, after frosting, in hot linseed oil, allowing the excess oil to drain off and finally heating to 400° C. The oil is partly decomposed, and particles of carbon are liberated which penetrate the surface, and a deep black firmly-adherent coating results. Care should be taken not to exceed 400° C. during the heating or the coating will be blistered. The finish obtained by this process differs from that obtained by the others previously discussed in that it is bright and hence would be unsuitable for camera parts or other applications where a dull matt surface is necessary.

It may be remarked that for such purposes black lacquer is often used without any initial chemical process. Aluminium, after light frosting, will hold a lacquer very well, and an excellent dull black finish, by no means easily removed, is obtainable by this means.

An alternative method which appears to be satisfactory without necessitating lacquer is black nickelling in the electroplating shop, using an ordinary black nickel solution, such, for example, as the following :—

Nickel-ammonium sulphate (double nickel salts)	8 ozs.
Zinc sulphate	1 oz.
Sodium sulphocyanate	2 ozs.
Water	1 gall.

The articles to be blackened are immersed in this solution without any previous preparation other than a cleaning, preferably by the sand blast.

Anodic Oxidisation.

The oxide of aluminium is normally invisible on the surface of the metal owing to its extreme thinness, but means are available whereby it can be thickened up until it appears as a white matt coating. The process adopted for thickening up the oxide coating must be such that a uniform film is produced, and that the film is strongly adherent, and one of the most convenient methods is to make the aluminium article the anode of an electrolytic bath. Almost any electrolyte (e.g. sulphuric acid or sodium bicarbonate solution) is capable of producing an oxide deposit on the aluminium under these conditions. The arrangement is as for ordinary electric plating, except that aluminium acts as the anode, while the cathode can be of lead, iron, or carbon. The main difference lies in the fact that the electrical resistance of the bath automatically increases as the oxide film forms, so that the current gradually dies off, and for this reason it is necessary to commence with a comparatively low voltage across the bath, increasing it gradually as the current falls. A maximum voltage of about 50 volts will be necessary, and means must be provided for reducing this down to a very few volts for starting. The most convenient and economical method is to use a shunt-wound dynamo with a field rheostat, as shown in Fig. 63.

The nature of the oxide film varies according to the electrolyte employed, and while with certain solutions the oxide is deposited in a somewhat spongy condition, with others the deposit is a glassy, strongly adherent, impermeable coat. Of all the possible electrolytes it appears that the most satisfactory is a solution of 3 per cent. of chromic acid, and this

forms the basis of a patent by Messrs. Bengough and Stuart.* With this solution it is found that the oxide film has a remarkably protective effect against corrosion, and is at the same time so firmly adherent that it can only be removed by such drastic methods as filing. Aluminium objects treated by this process have been exposed to the sea for months in such a position that they are periodically wetted and dried under the action of the tides, without showing any trace of corrosion, and good results were obtained even when the aluminium article was clamped to some other metal. Thus, apart from the purely decorative effect of the oxide film, this process has a special value where the article is to be exposed to adverse conditions.

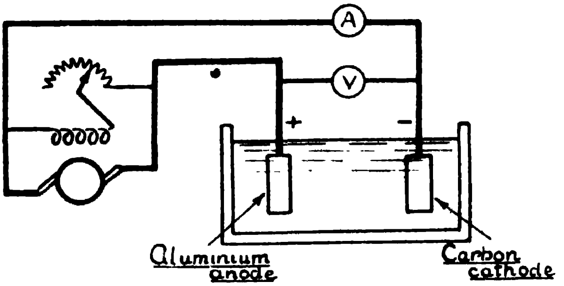

FIG. 63.— Electrical connections for anodic deposition on aluminium.

It may here be remarked that the decorative effect depends to some extent upon the nature of the metal under treatment. With pure aluminium the deposit is matt white, but with alloys the coating takes on a greyish appearance more or less dark according to the composition. With silicon alloys the process gives a very striking gun-barrel finish.

The process is not applicable to every type of alloy. In particular with copper alloys containing more than 5 per cent. of copper the current required is high and the objects may become deeply pitted during the process. Silicon alloys containing up to 12 per cent. of silicon are quite readily treated,

* British Patent No. 223,994, 1923.

as also are duralumin, and zinc alloy castings containing up to 12 per cent. of zinc.

The chromic acid should be pure, and free from sulphates and sulphides, and if the best results are to be obtained the temperature of the bath should not be allowed to rise above 40° C. A description of the process and the various experiments made with it is contained in a pamphlet issued by the Department of Scientific and Industrial Research * in which the standard treatment for pure aluminium and for duralumin is described as follows. After a preliminary washing in petrol to remove all grease, the metal is immersed in the bath and the voltage is gradually raised from zero to 40 volts in 15 minutes. It is then held at 40 volts for 15 minutes, raised to 50 volts gradually in 5 minutes, and held at 50 volts for 5 minutes. The object is then washed in water and dried. A current density of about 3 amps. per sq. ft. is required for pure aluminium, though this varies with the nature of the surface and the purity of the metal. If the aluminium has a local spot where some other metal is embedded in it, or is in contact with any other metal during the treatment, a very high current will be taken and the treatment becomes impossible.

The film appears to have a microscopic cellular structure in that it can absorb a certain amount of grease, and when the film is reinforced in this manner the protective effect is still further increased. A suitable impregnating substance is lanoline applied as a 10 per cent. solution in benzine.

Dyeing.

Aluminium oxide is a mordant used in certain classes of textile dyeing, its function being to absorb and fix the dye within the fibres of the material. It will be understood, therefore, that if an article of aluminium freshly coated with aluminium oxide by the electrolytic process, be dipped into a suitable dye the oxide film will be strongly and permanently

* "The Anodic Oxidation of Aluminium and its Alloys as a protection against Corrosion," published by H.M. Stationery Office, 1926.

coloured. This process, which is also patented by Messrs. Bengough and Stuart,* is capable of giving some very beautiful effects. Among the dyes which may be used are—

Alizarine orange.	Alizarine delphinol B.
Anthraquinone blue.	Alizarine yellow L.
Anthracene blue.	Solway blue S.E.
Alizarine celestol B.	Solway blue-black B.
Alizarine red S.	Solway green E.

All these produce brilliant colourings which are not removable without removing the oxide film, and this, as has been stated, is only possible by machining, or by some other method which removes the underlying metal as well. Dyed sheets of aluminium can be bent to a considerable angle without cracking, and are as well fitted to withstand the wear and tear of ordinary use as the best enamel coatings.

The appearance of the dyed metal is quite different from that of an enamelled finish, because the coating is microscopically thin so that there is no appreciable rounding of edges due to its presence, and also the sheen of the metal beneath is not entirely lost. The difference between the two processes is, in fact, analogous to that between a water-colour picture and an oil painting.

Etching.

An effective method of decorating ornamental goods, in which a pattern is developed by polished surfaces standing out in light relief against a frosted background, is the process of etching, of which many systems are in use. In essence the process consists of coating the parts of the article which it is desired shall remain bright, with a compound which will resist chemical attack, and then to immerse the whole article into an etching solution. The etching solution for aluminium may be hydrochloric acid or caustic soda solution, and a good "resist" is asphaltum varnish thinned with turpentine to the proper consistency. Shellac, which is often used with an acid etch,

* British Patent No 223,995, 1923.

is a poor resist to caustic soda. Caustic soda dissolves most vegetable gums though gum benzoin dissolved in amyl alcohol and coloured with a suitable dye, would resist long enough to permit light etching. After etching is finished the resist is removed by washing in methylated spirit or wood naphtha.

A number of different systems are in use for applying the resist. Where the design is a bold simple one, as, for example, a name-plate, the varnish can be applied by hand or through a stencil. More complicated patterns are dealt with by a process in which the pattern is printed on to a sheet of tissue paper from a hand-engraved or photographically-etched copper plate. The " ink " used is made up with beeswax, asphalt and resin mixed up with turpentine so that it will act as a resist, and the pattern on the paper is transferred to the metal article while the ink is still wet. The paper is then washed off, leaving the article marked out with the required pattern, and ready for the etching bath.

Engraving.

Engraving upon aluminium which has previously been frosted, is a form of ornamentation very popular for souvenir ash trays, cigarette boxes, etc. The design chosen should be of an open type such as is produced by a broad flat tool, because the chief beauty of the result lies in the contrast between the bright surfaces of the cuts and the matt background of the initial surface. The ordinary engraving tools as used with copper are suitable for aluminium, but it is necessary that the edges be kept exceptionally keen. The oilstone, therefore, forms an essential part of the equipment, as also does a " buff stick," consisting of a flat piece of boxwood smeared with a paste of putty powder, which the worker employs freely to maintain the keenness of edge.

A lubricant is also necessary, and methylated spirit or a mixture of three parts of turps and one part of stearic acid are both satisfactory. The lubricant is kept in a cup by the side

FIG. 64.—Indian repoussé work in aluminium.

[*To face page* 205.

of the worker, and he dips his tool into this from time to time as he proceeds.

Repoussé Work.

Repoussé work, in which a design in high relief is formed on a sheet by pressure from the back is hardly a commercial process, though the great ductility of aluminium enables some very beautiful results to be obtained when time and cost are of little importance. Some particularly good examples are shown in the photograph (Fig. 64), which represents a number of Indian productions. Work of this kind is, of course, far too slow to have any but very limited application, but the same general principle is adopted in a form of finish which is very effective for certain kinds of work. In this a sheet of brightly-polished aluminium is covered all over with light hammer blows, forming a series of small dents about quarter of an inch in diameter. The work is done on a leather block or a block of rubber, using a lead-nosed mallet. Light blows are all that is necessary, but care should be taken to direct them at the right spot so that each place is hit once only.

Painting.

The bodywork of motor-cars, when made in aluminium, is usually painted in the same way as steel bodywork, not so much for the purpose of protection against corrosion, but rather to provide an artistic colour scheme and at the same time to relieve the owner of the trouble of keeping the body bright. Aluminium takes paint very readily if the surface is given a preliminary roughing, either by frosting or by rubbing down with emery cloth. The metal must, of course, be completely freed from grease, if necessary by a preliminary washing with benzine or petrol, and if the frosting is done with caustic soda it is necessary to take special care that the soda is thoroughly washed away before proceeding with painting.

The number of coats of paint required tó produce any given finished effect is found to be considerably smaller with

aluminium than with steel, because aluminium is much more readily finished with a completely flat surface. Steel, however highly planished, will generally exhibit small surface irregularities visible in oblique lights, which are only hidden by the application of many filling coats and much rubbing down. The following figures represent the standard practice of a British railway company which constructs coaches of aluminium, steel, and wood, and they amply illustrate the point :—

	Wood.	Steel.	Aluminium.
Priming coats	2	1	1
Filling and rubbing down coats.	4	2	Nil
Body colour coats . . .	3	3	3
Varnish coats	3	3	3
Time (days)	15	13	10

The practice of other coach-builders will probably vary considerably from these figures, but in all cases the economy of aluminium from the point of view of saving of paint and time is well established.

The same kinds of paint are used with aluminium as with other metals, but it is desirable that white lead mixtures and other base pigments should not be used in direct contact with the metal. The initial priming coat should be of gold size, japan, or a mixture of raw linseed oil and quick-drying varnish, and after the application of this there is then no objection to using a white lead base for the coats which follow. The objection to a base pigment is that, as is well known, aluminium is subject to chemical attack by alkaline substances, so that blistering may occur unless a neutral priming coat is employed. It may here be remarked that for the same reason it is desirable that the filling between aluminium panels and the sole bar should be a bituminous compound instead of the more commonly employed white lead.

A modern development is cellulose enamel in which nitrocellulose or cellulose acetate is dissolved in amyl acetate or some other suitable solvent, together with a gum resin to

provide adhesiveness, and some material such as camphor or castor oil to add to the elasticity of the coat. Such materials provide an extremely hard coat which will itself take a good polish and is much less vulnerable to scratching. Another outstanding feature of these enamels is the rapidity with which they dry. The enamel is applied by a sprayer, and after one hour the coat is dry and hard, so that three finishing coats can easily be applied in one day. This is a very considerable advantage, and for this reason attempts have been made to omit linseed oil paints entirely, and to apply the cellulose composition direct to the metal without the preliminary use of primers and fillers. Unfortunately the cellulose enamel does not flow well, and is a much thinner material altogether than ordinary paint, so that its power to obliterate scratches and surface defects is much inferior. Moreover, if applied directly to the metal it does not adhere so well, and is apt to peel and crack, especially at the edges of beadings. For high-class work, therefore, the surface of the metal is often prepared for cellulose enamel in the same way as for ordinary enamel, the undercoats being of ordinary paint, but mixed with the minimum quantity of oil in order to provide the maximum of hardness.

Stove Enamelling.

Stove enamel is not usually applied to sheet-metal articles in aluminium owing to the annealing effect of the heat required, but this does not apply in the case of castings, and the process is quite readily applicable if a comparatively low temperature enamel is used. Stove enamels are available designed for baking at about 300° F., and these are quite suitable for aluminium.

The surface of the article should first be prepared by frosting, or preferably by sand blasting, and after this the procedure is exactly the same as for other metals, the enamel being applied warm to warm metal, and the temperature of the stove raised gradually. For the final coat the temperature of the oven

should be maintained at about 200° F. for 30 minutes and then gradually raised to the temperature recommended by the makers for the particular enamel employed.

Cleaning Aluminium.

Though aluminium is claimed by the makers to be "rustless" this does not mean that it will keep its brilliant polish in all degrees of exposure for indefinite periods, and, as with every other metal, the continued action of damp air will necessitate periodic cleaning. The amount of cleaning required is not more than that usual with nickel-plated articles, and a motor-car with an unpainted aluminium body can be left out in all weathers without risk of a permanent loss of its polish, provided that it is given a reasonable amount of attention periodically.

A satisfactory method of treating a polished car body is to give it the same treatment as if it were enamelled, i.e. it should be given a regular wash down with clean water, dried off with a clean chamois leather and finally rubbed up with a clean duster. Polishing, as ordinarily known, is then only wanted at very rare intervals, and when a reviver is necessary an ordinary good quality liquid metal polish can be used. An alternative is a mixture of whiting and paraffin oil which is said to be especially effective for aluminium.

In the use of ordinary polishes it is desirable to use the smallest practicable quantity, and above all to employ *clean* dusters and rubbers. The surface of aluminium is readily scratched by minute particles of grit, and though such scratches may be extremely small they will spoil the brilliance of the result. With clean polishing cloths a good bright surface can be obtained on aluminium with a surprisingly small amount of rubbing.

Cooking utensils in aluminium are often neglected as regards their external polish, although if the process described above is regularly carried out, they can be preserved in a condition as good as new for many years. Cleaning, in the case of

these utensils, is usually confined to the removal of grease, and, as is well known, the makers of such utensils insist upon the slogan "use no soda." The reason is that washing soda, having an alkaline reaction, has a solvent effect on the metal, so that if an aluminium utensil is boiled in strong soda water the surface will be "frosted" and the metal gradually thinned. There may also be a darkening of the surface as has already been mentioned in connection with the frosting process.

The makers may be wise to emphasise the necessity of avoiding soda in cleaning, since undoubtedly if no warning were given, and the metal were subjected to the lavish use of hot soda water, usual with iron saucepans, the life of the aluminium would be curtailed. Nevertheless, there is no serious objection to a reasonable use of soda. The pinch or two usual when cooking greenstuffs need not be omitted, even though the saucepan is of aluminium. The solvent effect would be extremely slight, the amount of metal dissolved is infinitesimal, and the salts formed are tasteless and completely non-poisonous. The use of soda for cleaning is also not objectionable, provided that it is used with care. A rapid wash out with hot soda, followed by rinsing in clean water, would do little harm, though it would be bad to allow strong soda water to stand over-night in an aluminium pan.

Even the small amount of solution which would take place during a rapid washing in soda can be obviated if the soda be mixed with a small quantity of water-glass (sodium silicate). This material has the very remarkable property of producing immunity against attack by alkalies without in any way interfering with the solvent action of the alkali on fatty materials. Water-glass is not a material which is readily handled in the kitchen, but several cleaning compounds composed principally of washing soda and water-glass are upon the market, and sold in this country under such trade names as "Carbosil," "Pearl Dust," and "Aquamol." The use of these materials can be recommended for all classes of cleaning, since they have no frosting effect upon highly-polished aluminium.

The interior darkening of aluminium utensils which occasionally occurs on boiling certain kinds of water in them is thought to be due to the small percentage of iron impurities present in the metal, acting in conjunction with certain of the impurities in the water. This dark film is of extremely minute thickness, so thin, in fact, that a sufficient quantity cannot be obtained to permit a definite analysis to be made, and in consequence its exact nature is unknown. It is strongly adherent, and need not be removed at all, since it has a distinctly protective action, but if desired it can be removed by a weak acid. The mere stewing of fruit in the pan, for example, will render the interior clean and white, and it may be stated that the quantity of dark material is so microscopic that it will have no effect whatever on the fruit, nor be injurious to health. Alternatively, the pan can be cleaned by boiling in it some water acidulated with vinegar. The process is, of course, essentially the same as that employed in the frosting process, where the initial darkening due to the soda is removed by an acid dip. A similar process—dipping in nitric acid—is employed for removing the yellow streaks from castings which have become discoloured through pouring with metal which is too hot, or through other causes.

INDEX.